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A TREATISE ON THE

METALLURGY OF IRON.

A TREATISE ON THE
METALLURGY OF IRO

CONTAINING OUTLINES OF

THE HISTORY OF IRON MANUFACTURE,
METHODS OF ASSAY, AND ANALYSES OF IRON OR
PROCESSES OF MANUFACTURE OF IRON AND STEEL
ETC., ETC.

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FOURTH EDITION, REVISED AND ENLARGED

Illustrated with numerous Wood Engravings
FROM DRAWINGS BY J. B. JORDAN

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"Mir wüsse wie me's Eise macht
Und wie's im Sand zu Massle bacht;
Und wie me's druf in d' Schmidte bringt
Und d'Luppen unter'm Hammer zwingt."

HEBEL.

PREFACE.

THE importance of the subject has claimed for the Metallurgy of Iron much careful scientific investigation, both in this country and abroad; but being confined, for the most part, to large and expensive works, or to the pages of scientific periodicals, it is scarcely available for the technical education of the great class to whom a general knowledge of the physical properties of the ores, and the latest and most approved means of reducing them to a condition suited for the purposes of the manufacturer, is desirable.

To supply this want is the chief object the author has had in view in producing this volume, which he believes will furnish much information that practical workers of iron, students, and owners of iron mines require, in a condensed and portable form.

A work of this nature, as a matter of course, must in a great measure be a compilation from the larger modern publications on the same subject. The author acknowledges his obligations to the following published abroad:—

Baer.—"Das Eisen," and the Swedish edition by Akerman.
Karsten.—"Eisenhüttenkunde."
Kerl.—"Hüttenkunde," vol. iii. 2nd Edition.
Rittinger.—"Erfahrungen."
Tunner.—"Stabeisen und Stahlfabrikation."
"Report on International Exhibition, 1862," in the *Leoben Jahrbuch.*
Wagner's "Jahresbericht für technische Chemie."
"Berg und Hüttenmännische Zeitung of Freiberg."
"Oesterreichische Bergwerks Zeitung."
Ansiaux and Masson.—"Fabrication du Fer," &c.
De Vathaire.—"Etudes sur les Hauts Fourneaux."
Grüner and Lan.—"Métallurgie du Fer en Angleterre," &c., published in the *Annales des Mines.*
Jordan.—"Métallurgie du Fer au Pays de Siegen," published in De Kuyper's *Revue Universelle.*

He has also perused with considerable advantage, especially in regard to our Iron Works—Percy's "Metallurgy of Iron and Steel," Truran's "Iron Manufacture of Great Britain," Noad's article "Iron" in "Ure's Dictionary," and articles on Iron Works in "Engineering."

The illustrations, drawn by Mr. J. B. Jordan, have mostly been reduced from large-scale drawings, especially those published by the Technical Institute of Berlin, under the title "Zeichnungen für die Hütte."

London, *March,* 1868.

PREFACE TO THE THIRD EDITION.

In preparing a new edition of this work, to be issued in the series for which it was originally designed, advantage has been taken of the opportunity to bring it up to the present time by the insertion of notices of the principal facts and processes in connection with iron making, that have been made public during the interval of four years that have elapsed since the work was written. These additions have been introduced in their proper places in the original text. Among them will be found notices of the Siemens-Martin steel process, probably the greatest advance made in iron-metallurgy since Bessemer's great invention, as well as the various plans proposed by Heaton, Ellerhausen, and others. During the final revision of the sheets, the Proceedings of the South Staffordshire Meeting of the Iron and Steel Association were published, containing many papers which appear to be of great immediate interest, and therefore notices of some of these have been given as additional notes.

The present is the third edition, the second having been issued for circulation in America, with the addition of a preface and appendix on the Siemens-Martin process, by an eminent American iron-master, Mr. Abram S. Hewitt, of New Jersey, who is well known by his elaborate and exhaustive report on the Metallurgy of iron as exhibited in Paris in 1867

LONDON, *September*, 1871.

PREFACE TO THE FOURTH EDITION.

THE last edition having been exhausted sooner than was anticipated, advantage has been taken of the opportunity of a re-issue to make some additions descriptive of processes recently introduced, namely, the rotative furnaces of Messrs. Danks, Spencer, and Siemens, and the application of the latter to the production of wrought iron directly from the ore. It may be as well to state, in answer to numerous inquiries, that the atomic formulæ throughout are those of the old notation.

LONDON, *February*, 1874.

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METALLURGY OF IRON.

CHAPTER I.

INTRODUCTORY AND HISTORICAL SKETCH.

THE subject of iron-smelting is the largest and most important in the whole domain of metallurgy, and, at first sight, presents a remarkable contrast to all other branches of the smelter's art. For in the case of most of the other metals employed as such in the arts, we have, as sources of supply, a numerous class of minerals varying greatly in richness and composition, and susceptible of reduction to the metallic state by processes also differing greatly among each other; while, in the case of iron, the few minerals that can be made useful as ores are restricted within much narrower workable limits, and form only one class of chemical compounds, namely, oxides, whose reduction can be effected practically only by one agent—that is, carbon or carbonic oxide. But as a very high temperature is necessary to effect the reduction, the metal almost always combines with a greater or less proportion of the reducing agent, as well as of other elementary substances, such as silicon, sulphur, and phosphorus, that may be present either in the ore, the fuel, or the flux, so that the ultimate result is never a pure metal, but a series of compounds, varying in properties from great hardness to perfect malleability, and from ready fusibility to almost absolute infusibility.

Practically speaking, absolutely pure iron may be said to be of no commercial value. But, on the other hand, extraordinarily small traces of foreign elements exert a very marked influence on the metal, and it is precisely these small and, in many cases, unnoticed differences of composition, that render so many points in the chemistry and practical working of iron obscure and difficult to be understood. When it is considered that the investigation of such problems calls for researches involving the utmost refinements of analytical chemistry, it is not remarkable that contradictory statements and opinions still abound on many points of the chemistry of iron-making.

The mechanical considerations involved in this subject are almost as important as the chemical; for, unlike the smelter of other metals, who is able by fusion alone to bring his finished product to a merchantable state, the iron smelter has to deal with pasty infusible masses, which require to be compacted and moulded by pressure by powerful machines, such as hammers, presses, rollers, &c., before they can be made available for consumption.

In view, therefore, of the great magnitude of the subject, it may be as well to state, at starting, that the treatise now placed in the reader's hands is devised to furnish such information connected with the metallurgy of iron as may be necessary for the elucidation of the general principles upon which the processes used in the reduction of iron from its ores are based. While, therefore, referring the student for the detailed discussion of the various points to the larger works on the same subject,—such, for example, as the elaborate volume published by Percy, in this country, and those of Karsten, Flachat, Valerius, Julien, Tunner, and others on the Continent,—we shall proceed to notice in as succinct a manner as possible, the principal facts and opinions current in the modern practice of iron-smelting under the following general headings:—

1. Outline of the chemistry of iron from the metallurgical point of view, noticing only such compounds as immediately interest the smelter.
2. Composition modes of occurrence and distribution of the ores of iron.
3. Methods of assaying, mixing, and fluxing ores.
4. Description of processes whereby the ores are reduced to the metallic state.

Before entering upon the consideration of the above subjects, it will be convenient to state broadly the nature of the finished products of the iron smelter's labour, and to glance rapidly at the historical part of the subject.

Of the Products of Iron Smelting—Cast Iron—Malleable Iron—Steel.

Iron is employed in the arts under three several states, whose variable properties are mainly due to differences in the quantity of carbon present, and in a lesser degree to that of other foreign matters. When alloyed with a maximum of the latter element, an amount which in ordinary smelting does not exceed 6 per cent., or fall below 2 per cent., the substance obtained is known as cast iron or *pig metal*. This is a hard and comparatively brittle substance, which can be readily fused at a high temperature, and is susceptible of being moulded into solid forms by casting, but also in most modern iron works forms an intermediate product in the manufacture of the other classes. According as the metal may be most adapted for founders' or forge-masters' use, it is distinguished as forge or foundry pig.

Wrought or Malleable Iron. This, the nearest approach to the chemically pure metal that can be obtained on the large scale, may be almost absolutely free from carbon, and never contains more than 0·25 per cent. It is a soft, malleable, and extremely tenacious substance, infusible, except at the extreme temperatures obtainable in furnaces of special construction, but capable of being agglomerated by pressure, when at a white heat, to a compact state by the process of welding. When heated and suddenly cooled, it retains its softness. It may be produced either directly from the ore or by the conversion of pig iron. The varieties of malleable iron are distinguished by many different names, but these have reference rather to form and destination than to differences of composition.

Steel. Those varieties of iron in which the amount of carbon is above the maximum of malleable, and below the minimum of cast metal, are known as steel. The distinguishing property of this class of products is the power of being hardened or softened at pleasure, by sudden or rapid cooling, by the process known as *tempering*. Being intermediate in position between wrought and cast iron, steel is both fusible and malleable, but requires a higher temperature for fusion than the latter, and greater compressing power, owing to its lower welding temperature, than the former. Those varieties that are richest in carbon are the hardest and most fusible, and are known as *strong steels*, while those that are nearer malleable iron in composition are distinguished as *mild steels* or *steely irons*. Steel may be obtained either direct from the ore at one operation, or indirectly by a variety of processes of greater or less complexity from either cast or wrought iron.

Outline of the Progress of Iron Manufacture. The history of the production of iron is probably almost co-extensive with that of the human race; at least, it goes back far beyond the periods of authentic history. According to the Pentateuch (Gen. iv. 22) the discovery of iron is attributed to Tubal Cain, who is said to have been sixth in descent from Adam. Pagan tradition assigns the discovery to Vulcan, placing it about the time of Deucalion's deluge. There can be little doubt that the discovery was made at a very early period, as the production of small masses of malleable iron is one of the simplest of all metallurgical operations, requiring only a small furnace without blowing apparatus, such as can be made by digging a hole in the side of any bank exposed to the prevailing wind, a supply of easily reducible ore, and charcoal for fuel. Such processes as these have been described as in use in Africa by Mungo Park, and are still employed in Birmah; and probably something of the same kind is indicated by the tradition which ascribes the discovery of iron in Scythia to the effects of forest fires in districts containing iron ores, when portions of the reduced metal are said to have been found among the ashes of the burnt trees.

It may have been, however, that the masses of iron referred to were meteorites, whose existence was first made apparent by the clearing of the ground.

Homer refers several times to iron and steel. Thus in the twenty-third Iliad, Achilles, at the funeral games of Patroclus, gives a disc of iron as the prize; and in the ninth Odyssey, the hissing of the burning stake that Ulysses plunges into the eye of Polyphemus is compared to the noise produced when steel is hardened by quenching it with water when at a red heat.

Probably the first important improvement in the manufacture was the introduction of the artificial blast, which is of great antiquity. In Egyptian sculptures of the reign of Thothmes III. (1505 B.C.) smiths are represented working at a forge, which is provided with two simple leather bellows, worked by the pressure of men's feet for the exhaust, and inflated by strings pulled by hand, in a manner exactly similar to that still employed in Birmah.

Aristotle (B.C. 384-322) describes the process of making cast steel used in India, which is still produced under the name of *wootz*; and also the manner in which the Chalybes of the Euxine procured iron. Pliny (A.D. 23-79) mentions the great masses of iron ore still worked in Elba, Styria, and Spain, and describes the methods of making iron and steel, especially remarking that the quality of the latter depended upon the water used in quenching, and that small tools were tempered in oil. ("Natural History," bk. xxxiv. chap. 41.)

Diodorus (B.C. 60-40), in describing the iron works of Elba, states the ore was reduced to small pieces and heated in furnaces; the charge, when properly softened, was removed and divided into small masses, which had a spongy appearance (blooms), and were exported to the main land of Italy for conversion into tools.

Galen (A.D. 131) remarks that knives made of Indian iron (steel) were remarkable for their strength and hardness, but were often so brittle that the cutting edge splintered off, owing to their having been improperly tempered.

According to Frañquoy, bellows with valves were introduced by the Romans into Gaul during the fourth century A.D. These, although single acting and made of leather, were a considerable advance upon the savage form, which required strings for their inflation. The wooden double bellows, which are still in use in some parts of the Continent, may be regarded as the precursors of the cylinder blowing engine, and were introduced into the Harz about 1620, either from Franconia or Thuringia.

During the middle ages the great improvement consisted in the gradually increasing height of the furnace, consequent on the use of ores of an infusible and difficultly reducible character. This necessitated a special means of withdrawing the reduced mass of iron (lump or bloom), which was effected through a lateral opening in the hearth, or lower part of the furnace, instead of being lifted out from above, as was done with the ordinary open fire. With the increased length of the operation, the reduced metal being left for a considerable time in contact with the fuel, facility was given for a greater absorption of carbon, resulting in the formation of a larger quantity of molten pig iron, which was run out with the slag, than was the case with the open fires. The increased height of the furnace is well seen in Agricola ("De Re Metallica," lib. xii. edit. 1546), who describes two different methods of iron-working as common in his time. The text is not very clear, but the engravings represent, in the first case, an ordinary bloomery, in which malleable iron is produced directly from the ore, together with a certain quantity of hard or pig iron; while, in the second method described as in use with refractory ores, the furnace has a shaft of such a height that the furnace-man requires to ascend a short flight of steps to reach the throat, or charging-place. It is surprising that this author makes no mention of foundry work; but as he states that the "hard iron" of the bloomery was useful for stamp heads, he was probably acquainted with the use of iron castings, but not with their mode of manufacture. The omission may also be accounted for by supposing that no foundries existed in Saxony, to which country most of Agricola's descriptions refer, until some time after their establishment in the Rhenish and Low Countries. The subject of iron-founding is noticed by Lazurus Ercker in his "Probierbuch," published in 1574. Karsten supposed that the *Stückofen*, or high bloomery furnace above referred to, was of Eastern origin, and was first introduced into Styria, travelling thence westward to Burgundy and Alsace, subsequently returning eastward into Bohemia and Saxony; and that the later forms of *Blauofen* and high furnace (the prototypes of the modern blast furnace) were invented in the Netherlands. The first indications of the latter are found in Lorraine and in the German Rhineland. Franquoy, who seeks with patriotic zeal to establish the priority of invention of the blast furnace to the Liège district, states that according to documentary evidence the *hauts fourneaux* at Vennes and Grivegnée in that country were established before A.D. 1400, and also that the furnace at Marche les Dames was built by William, Count of Namur, A.D. 1340. Karsten, on the other hand, states that although the knowledge of pig iron dates from time immemorial, its use and systematic production for foundry purposes cannot be traced back with certainty to an earlier period than the end of the fifteenth century.

In England, the blast furnace was probably in use at a very early period, as we have evidence, according to Lower, of ornamental castings being made in Sussex some time in the fourteenth century. The principal seats of the iron trade at that period in England were in the great forests of Sussex, Gloucestershire, and South Wales, where, under the older forms of bloomeries, iron works had existed since the days of the Romans. The gradual diminution of the forests of Sussex under the demands of the furnace, a process of destruction which may be seen going on at the present time with increased rapidity in Sweden, North America, and other countries producing charcoal iron, led to the passing of a stringent act in 1584 (27th Elizabeth) forbidding the further erection of iron works in the Weald of Sussex except under certain limitations. With the commencement of the seventeenth century came the first attempts at smelting with mineral fuel, the pioneer of this particular improvement being Dud Dudley, who in 1619 produced both pig and wrought iron with coal in Worcestershire; but the scheme was unsuccessful, owing to the opposition of the charcoal iron masters, so that after trials in several localities extending over upwards of thirty years, all of which ended unfortunately, the inventor finally abandoned the subject. A similar trial was made in Hainault by Octavius Strada, a native of Bohemia, in 1625, who obtained a monopoly of the invention for twenty-five years, but it led to no practical results. It was not till more than a century later, namely, in 1735, that the problem of smelting with coal was successfully solved by Abraham Darby, of Colebrookdale, who was the first to use coke in the blast furnace, an improvement which spread rapidly into all other iron-producing districts situated on or near the coal measures. The last furnace in the Weald of Sussex, at Ashburnham, was blown out in 1829, and there are now only two or three scattered representatives of the ancient charcoal furnaces remaining in the whole of the United Kingdom. The century following the success of Abraham Darby is marked by the introduction of the two great inventions which especially distinguish the modern period of iron manufacture; that is, the substitution of the reverberatory furnace for the open fire in the forge, and the use of heated air in the blast furnace. The former change effected by the puddling process, invented by Cort in 1784, has almost superseded all the older methods of making malleable iron; and the latter, due to Neilson and Condie, and first used at the Clyde Iron Works in 1828, has greatly increased the productive power of the blast furnace, with a diminution in the consumption of fuel.

Since the introduction of the hot blast, the chief improvement in the blast furnace is that of intercepting the gases, which were formerly allowed to burn to waste at the throat, and leading them off by distributing pipes, to be usefully employed as fuel under steam boilers, hot blast stoves, &c. This was patented in France in 1811 by Aubertot, the gases being employed for heating steel furnaces. In 1832 the waste gases were used for heating the blast at Wasseralfingen, in Bavaria, and a similar apparatus was first erected in this country in 1848 by J. P. Budd, at Ystalyfera, in Glamorganshire, since which time various modifications of the same plan have been adopted to a considerable extent, especially in those furnaces that are obliged to draw their fuel from a distance, but in other districts, as for example in South Staffordshire and Scotland, the old flaming throats still prevail.

Within the last few years, the chief inventions and improvements have been in steel manufacture, and many new processes have been introduced. Prominent among these is that named after its inventor, Henry Bessemer, which, although only of a few years' standing, has already effected important services by the production of a material admirably adapted for use in railway and other engineering work in place of wrought iron. Perhaps the problem of most immediate interest at present is that of the economical substitution of mechanical for manual power in the process of puddling, so as to enable the forge-master to manipulate larger masses of malleable iron at a time, and thus to put him more nearly on an equality with the cast-steel maker than is the case at present.

With the exception of the Weald of Sussex, very little change has taken place in the position of our principal iron-working centres from the earliest time down to the present day. Since the great expansion of railways several new and important localities have been brought into work, the ores being carried to the fuel or the reverse, according as might be most advantageous. In this way the great northern coal field of England, which is almost absolutely without ironstone, gives rise to the largest production in the kingdom by feeding the Cleveland district with coal and coke, and drawing ironstone for its own furnaces in return. The prevalence of cheap ores in the oolitic districts has brought the blast furnace to within fifty miles of London in Northamptonshire, and the pastoral districts of Wiltshire have been invaded by the same visitor. It need not, therefore, be a matter of much surprise if at some future period the Wealden furnaces were to be re-lighted, as they could be easily supplied with fuel from the western coal fields should the supply of ore be sufficient to warrant the attempt, especially as on the opposite coast of France large furnaces have been established for smelting ores out of the same formation, and which are supplied with fuel from England.

CHAPTER II

OUTLINE OF THE CHEMISTRY OF IRON.

The chief chemical points involved in the metallurgy of iron will next be briefly noticed under this head, in the order adopted equally by Karsten in his classical "Eisenhüttenkunde," and also by Percy, commencing with the pure metal, and proceeding to notice the principal compounds with other elements, metallic and nonmetallic, that are of importance from a metallurgical point of view.

Metallic Iron. This may be obtained in a chemically pure condition by reducing peroxide of iron by hydrogen at a red heat, or by re-melting the purest varieties of malleable iron with an oxidising flux, in order to remove the last traces of combined carbon. It may also be deposited by electrolysis from a solution of protochloride of iron, in the form of brilliant malleable films,—a process that has been employed by engravers to protect the face of engraved copper plates from undue wear during printing, and is known as *acierage,* or steel facing. It does not appear to be quite certain, however, from the contradictory statements made by different observers, that electro-deposited iron so obtained is absolutely free from nitrogen.

The physical properties of the metal vary very considerably, according to the means adopted for its production. When obtained by reducing peroxide of iron by hydrogen at the lowest possible temperature at which the change can be effected (according to Magnus between 600° and 700° F.), it forms a dark grey powder, which combines energetically with oxygen, taking fire spontaneously when slightly heated and thrown into the air. When, however, the reduction takes place at a higher temperature, the metallic powder agglutinates to a sponge of a filamentous texture, a silvery grey colour, and metallic lustre, which is no longer pyrophoric.

Larger and more compact masses may be obtained by removing the last traces of carbon and other foreign substances from the purest commercial wrought iron in the following manner :—A small quantity, from 300 to 500 grains, of good wrought iron, such as pianoforte wire or Russian black plate, cut up into small pieces, and either rusted by exposure to steam or mixed with about 20 per cent. of pure peroxide of iron, is to be melted under glass free from metallic oxides, in a refractory crucible, at a strong white heat, the operation requiring about an hour's full heat of a good wind furnace. The small quantity of carbon present in the metal is expended in reducing a portion of the sesquioxide, the remainder passing into the slag; the result being a brilliant well-melted button of metal, which exhibits a decidedly crystalline structure, similar to that observed in meteorites when treated with an etching liquor, and is somewhat softer, but less tenacious, than the iron originally employed. Another method of obtaining iron absolutely pure, or nearly so, has been recently adopted by Matthiessen in an experimental research into the composition of cast iron. A mixture of protosulphates of iron and soda, in nearly equal proportions, are fused in a platinum crucible until the evolution of sulphurous acid gas ceases. The iron is left as a finely crystalline peroxide, and may be separated from the fused mass by treatment with water, the last traces of sulphuric acid being removed by long and careful washing. The peroxide so obtained is reduced to the spongy state by hydrogen, and the spongy metal, after being consolidated by pressure in a steel mould, is melted in a crucible, made of caustic lime, before the flame of the oxyhydrogen blow-pipe. The metal produced by this method is said to be free from phosphorus, silicon, and calcium, but contains a minute trace of sulphur.

The electro-deposition of iron has recently been effected, on a comparatively large scale, by Jacobi. Instead of the protochloride, a solution of the double sulphate of protoxide of iron and magnesia is used, care being taken to keep the solution as nearly neutral as possible. The strength of the electric current must be regulated so that very little hydrogen is evolved.

Electro-deposited iron obtained by this process is exceedingly hard and somewhat brittle, but, on annealing, especially in hydrogen, it becomes malleable, soft, and silvery-white. The specific gravity is 7·675 in the state of original deposition, which is increased by annealing to 7·811, in the same manner as ordinary malleable iron or steel. Like palladium, it possesses the power of dissolving or occluding hydrogen, though to a considerably smaller extent. By heating the deposited iron in vacuo it gives up from seventeen to twenty times its volume of hydrogen.

According to Lenz (*Pogg. Ann* 1870, vol. v., p. 242) the properties of electro-deposited iron vary very considerably according to its subsequent treatment. When the iron is deposited by a weak current from a solution containing no free acid, it is of a fine granular texture, not showing a crystalline structure under the microscope, and exceedingly hard, so that it can scarcely be touched by the file. The hardness is given, according to the mineralogical scale, as 5·5, or intermediate between that of apatite and felspar. It is also remarkably brittle; thin plates can be rubbed to powder between the fingers, and even a piece $\frac{1}{12}$ of an inch in thickness was easily broken. By annealing over a charcoal fire, the hardness is reduced to 4·5, *i.e.*, the iron scratches fluor-spur, but not apatite; and the brittleness is replaced by extreme softness and ductility; the thin plates, that crumbled when handled before annealing, becoming so tenacious that they may be repeatedly folded backwards and forwards even oftener than a sheet of paper without breaking. When heated in vacuo, electro-deposited iron changes colour, and becomes nearly as white as hammered platinum; at the same time a considerable quantity of the gases, absorbed during the reduction, are given off. The proportion between the volume of these gases, which consist chiefly of hydrogen, and that of the iron plate depends chiefly upon the thickness of the latter; the absorptive power diminishing as the thickness increases. In one instance a very thin film was found to contain 185 times its volume of occluded gases. The iron which has been deprived of its gases by heat is extremely susceptible to oxidation, and rusts rapidly when kept in water free from air; at the same time hydrogen is reabsorbed to a small extent, so that the oxidation is due to the decomposition of water by the iron at ordinary temperatures.

Action of Heat. The melting-point of pure, or even ordinary, malleable iron has not been determined with certainty. According to Pouillet it lies between 1,500 and 1,600° centigrade, while Scheerer gives it as 2,100° of the same scale. The linear dilatation by heat is $\frac{1}{846}$ between 0° and 100°, and $\frac{1}{227}$ between 0° and 300° C.*

Magnetism. Pure iron is susceptible of being magnetised to a much higher degree than steel, but unlike the latter metal, it does not retain its magnetism when the exciting cause is removed. The following determinations of the proportional magnetism of different compounds of iron are by Plücker (Müller's "Physik," vol. ii. p. 402):—

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* In future, except where otherwise stated, the temperatures will be expressed in centigrade degrees.

Magnetic power.—	Metallic iron	100,000
,,	Magnetic oxide	40,227
,,	Native peroxide	761
,,	Precipitated peroxide . .	714
,,	Solution, nitrate of peroxide	410
,,	,, protochloride . .	490
,,	Hydrated peroxide . . .	296

Specific Heat. 0·11379 according to Regnault, or 0·1100 by Dulong and Petit. The conducting power for heat is 374, gold being taken as 1,000 (Despretz). The electrical resistance (as determined by Pouillet) is 5·88 times that of a copper conductor of equal sectional area.

The crystalline forms of iron are most probably to be referred to the cubical system, although there is some difference of opinion on this subject. Fuchs supposed them to be in part rhombohedral, and that the metal is dimorphous; the balance of opinion is, however, in favour of the former view. The observed forms are the cube, octahedron, and tetrahedron. According to Peligot, brilliant cubical crystals are occasionally obtained when protochloride of iron is reduced by hydrogen in a porcelain tube at a red heat. The equivalent or atomic weight of iron is 28 when hydrogen is taken as the unit of the scale, or 350 when oxygen is taken as 100; its symbol is Fe.

Passivity of Iron. When a bright iron wire is immersed in fuming nitric acid, containing a certain amount of nitrous acid, it becomes passive; that is, it is not dissolved, even if placed in acid of the ordinary strength, as long as no great increase of temperature takes place. If, however, the temperature be raised, or the metal be touched by a copper wire, it is immediately attacked and dissolved.

If the experiment be tried with ordinary nitric acid, a violent action is set up, and goes on until the wire is completely dissolved; but by removing it from the liquid, and keeping it out until the adherent film of acid has become saturated, the face of the metal becomes of a dead white hue, and on re-immersion is found to have assumed the passive condition, which it retains until it is rubbed or polished. Steel wire, when similarly treated, gives rise to a violent ebullition for about twenty seconds, which suddenly ceases, and no further action takes place. This behaviour is characteristic of all varieties of steel, however they may have been produced, and is a good method of distinguishing them from soft iron, which is rapidly dissolved under these conditions. By placing a bar of steel and another of iron in the same acid, and bringing their ends which project beyond the liquid into contact, the latter is rendered passive, and remains so as long as the temperature of the liquid is not raised above 40°. Steel which has been rendered passive in the cold may be digested for an indefinite period in boiling nitric acid, without undergoing any perceptible alteration.

The cause of this peculiar property is not well made out; it is, however, supposed that it may be due to the formation of a very thin, but closely adherent film of oxide, which in some way acts like a varnish and protects the metal below from any further alteration.

According to the recent researches of Ordway, the maximum temperature at which passivity may be induced in malleable iron varies with the strength of the acid used.

Thus, with acid of specific gravity 1·38, iron is passive at 31°, but is attacked at 32°; with 1·42·

it is passive at 55°, but is attacked at 56°. With red fuming acid of specific gravity 1·42 iron is passive at 82°, but is attacked at 83°.

Compounds of Iron and Oxygen. Iron unites with oxygen in many different proportions, of which compounds three are simple oxides; but these combine among themselves into more complex bodies. The following are the simple forms, with their symbols, atomic weights, and percentage compositions:—

	Symbols.	Atomic Weight.		Percentage Composition.	
		Iron.	Oxygen.	Iron.	Oxygen.
Protoxide, or ferrous oxide	FeO.	28	8	77·7	22·2
Peroxide, sesqui-, or ferric oxide . .	Fe^2O^3	56	24	70·0	30·0
Ferric acid . . .	FeO_3	28	24	53·9	46·1

The first and last of the above compounds are very unstable substances, and have never been isolated, or at any rate with sufficient certainty to allow of a determination of their physical aad chemical characters. The peroxide, on the other hand, occurs abundantly in a nearly pure state, forming the hard and brilliant mineral known as *hematite* or *iron glance.* A lower oxide of the composition, Fe^4O, is said to be formed when iron is burnt in oxygen, but this is doubtful.

Protoxide of Iron. Although it has been generally stated that this oxide is too unstable a substance to be able to exist in an isolated state, yet according to Debray it is formed when mixtures of steam and hydrogen are passed over sesquioxide of iron at a red heat, provided that the proportion of the two gases to each other be not less than equal equivalents, or more than three of hydrogen to one of steam. With a greater proportion of hydrogen metallic iron is formed. The oxide so produced is said to be a non-magnetic black powder, which may be burnt in air, forming magnetic oxide. There are several known combinations of proto- and peroxide of iron. The most basic, and therefore the nearest approach to the pure protoxide, is found in the inner portion of the black magnetic scale which forms upon the surface of bar iron when heated to redness with access of air. The scale so formed, when of any thickness, is found to vary in composition from a nearly pure sesquioxide externally, to a substance which, although probably not a definite chemical compound, may be represented by the formula $6\ FeO + Fe^2O^3$ on the inside in contact with the metal. When the two oxides are combined in equal equivalents, a substance is formed which occurs largely in nature as a definite mineral, known as *magnetite* or *magnetic iron ore*, which crystallises in the cubical system, and is, as its name implies, distinguished for its magnetic properties. It is a member of the group of minerals known as the Spinel group, all of which crystallise in the same form, and have the same general formula of $RO + R^2O^3$; or, as it is sometimes contracted, R^3O^4; thus $FeO + Fe^2O^3 = Fe^3O^4$.

Hydrated Protoxide of Iron may be produced by precipitation from the solution of a protosalt by the addition of potash or soda. It is a white flocculent powder, which almost immediately becomes green from the formation of hydrated magnetic oxide. When freshly prepared, however, the protoxide is soluble in 150,000 times its own weight of water, to which it gives an alkaline reaction. It is a strong base, and unites readily with acids to form protosalts, which are mostly unstable compounds unless kept out of reach of the air, as they absorb oxygen with greater or less facility, and pass into the state of basic salts of the peroxide. The most important of these salts occurring in an anhydrous state is the *carbonate*, $FeO. CO^2$, which is found abundantly in nature crystallised in a pure state as *spathic iron ore*, or siderite, in isomorphous combination with the carbonates of lime and magnesia as *brown spar* and *pearl spar*, or in an amorphous state associated with a greater or less proportion of carbonate of lime and clay, forming concretionary nodules, or septaria, of clay ironstones and cement-stones in argillaceous strata of different geological periods.

Protocarbonate of iron is sensibly soluble in water containing free carbonic acid, forming a bicarbonate, which is retained as such as long as the solution is protected from the air, but is rapidly altered by absorption of oxygen into hydrated peroxide by exposure, as, for instance, when waters that hold iron in solution are exposed in ponds or swamps. This property has a most important bearing on the origin of ores, as it furnishes a means by which large masses of mineral may be elaborated from rocks comparatively poor in iron.

When heated to redness with access of air, protocarbonate of iron is decomposed, giving rise to the magnetic oxide, half of the acid being reduced to carbonic oxide in order to supply the necessary oxygen: thus—

$$2\,FeO. CO^2 = (FeO + Fe^2O^3) + CO + CO^2.$$

When iron-filings diffused through water which has been thoroughly deprived of air are subjected to the action of carbonic acid gas, the water is partially decomposed, hydrogen is evolved, and protocarbonate of iron is formed, which remains in solution until the excess of acid is removed.

Peroxide or Sesquioxide of Iron (Fe^2O^3). This oxide is largely met with in nature, both anhydrous, as *hematite, iron glance*, or *red iron ore*, a mineral having, when in its purest state, a bright metallic lustre, and crystallising in the rhombohedral system, and in combination with water forming various hydrates, among which are *brown hematite, limonite*, &c. It may be made artificially by calcining protosulphate of iron at a strong red heat, the salt, by its decomposition, giving rise to sulphuric and sulphurous acids, and a bright red pulverulent peroxide known as *rouge, colcothar*, or *crocus*, which is extensively used as a polishing material by glass and metal workers. The reactions in this process, which is employed commercially in the manufacture of fuming or Nordhausen sulphuric acid are as follows:—

$$2\,FeO.\ SO^3 = Fe^2O^3 + SO^2 + SO^3.$$

Pulverulent varieties of the same substance, but differing in colour and tenacity, may be obtained by the calcination of other salts of iron as follows:—1, from the pernitrate, which yields a nearly black product; 2, from the persulphide, giving a rouge suitable for goldsmiths—this requires a long-continued, and finally, rather a high heat; and 3, from the neutral protoxalate, which gives a very finely divided product.

A brilliant variety occurs in small steel-grey crystals in the hollows of lavas from Vesuvius and other volcanoes. One of the finest examples of this kind, brought from Ascension Island, is now in the Museum of Practical Geology. It may be artificially imitated by calcining protosulphate of iron at a strong red-heat with three times its weight of chloride of sodium. The latter salt is unaltered, and may be dissolved out with water; the residue is peroxide of iron in brittle and crystalline scales of a dark violet or nearly black colour. These brilliant varieties are distinguished by mineralogists as *specular iron*, *iron glance*, or *oligistic iron*.

Peroxide of iron is also found crystallised in regular octahedra in the mineral known as *Martite*, which belongs to the cubical system; it occurs in conjunction with the rhombohedral variety in lavas from Vesuvius and other localities, and also in the slaty hematites of Lake Superior.

The true composition of this mineral is rather doubtful. It has been sometimes considered as a pseudomorph of magnetite. Rammelsberg found in octahedral crystals from the eruption of Vesuvius in 1855 as much as 15 per cent. of magnesia, and has described them as magnoferrite. He is not, however, prepared to regard this as necessarily a new definite member of the spinel or R^3O^4 group, but considers it to be a dimorphous form of the peroxide, containing magnesia in isomorphous mixture, the peroxides and protoxides being capable of replacing each other without change of form. This view, if further extended, would make magnetite only a particular variety of octahedral hematite, in which the two isomorphous oxides are to each other in equivalent proportions, and would fairly explain the deviation in composition of nearly all magnetites from the theoretical formula — sometimes one and sometimes the other oxide being in excess of the required amount.

Peroxide of iron forms a series of salts parallel to those of the protoxide, but it is difficult to obtain them of a neutral composition, as their solutions have a tendency to decompose into basic and acid salts, the former usually precipitating, while the latter remain in solution.

At ordinary temperatures the peroxide is a very stable substance; it may, however, be decomposed by heating it nearly to a white heat, when magnetic oxide is formed with evolution of oxygen; thus—

$$3\,Fe^2O^3 = 2\,Fe^3O^4 + O;$$

a reaction which explains why magnetic oxide is produced when iron is burnt in oxygen, the temperature of the combustion being too great to allow of the existence of the higher oxide.

Hydrates of Peroxide of Iron. The hydrate produced by precipitation from the solution of a persalt of iron, or by spontaneous oxidation from the hydrated peroxide, consists of two equivalents of peroxide of iron combined with three of water, or $2\,F^2O^3.\ 3\,HO$. It forms the base of a large class of minerals known as earthy brown hematite or limonite, and is the ultimate product of the alteration of any substance containing protoxide of iron when exposed to the action of atmospheric air and moisture.

When boiled in water for seven or eight hours, the hydrated protoxide loses water, and is reduced to the form of $Fe^2O^3.\ HO$, which is a brick-red powder but slightly soluble in acids, and also occurs in nature beautifully crystallised in the minerals göthite, lepidocrocite, &c.

The last equivalent of water may be removed, and anhydrous peroxide obtained, by heating the hydrate in a solution of chloride of calcium, or common salt, for several days, at a temperature of 160° to 180°.

Hydrated peroxide of iron is sensibly soluble in water containing carbonic acid, or any soluble organic salt of ammonia, such as are produced by the decomposition of vegetable matter. In the latter case the solution is attended with a reduction, and the formation of a protosalt of the organic acid.

Magnetic Oxide of Iron. This compound, one of the most important commercial sources of iron, is formed of equal equivalents of the per- and protoxide, or $FeO + Fe^2O^3$, or short Fe^3O^4. It is a black mineral of high lustre, crystallising in the regular system, the commonest forms being either octahedra or dodecahedra, which may be artificially imitated by passing steam over iron wire at a red heat, when small brilliant black octahedra are formed on the surface of the metal. The natural mineral is always magnetic, often polar, and occasionally forms magnets capable of supporting considerable weights. The two latter conditions do not depend so much upon purity of composition as upon molecular structure, as they are best developed, not in the purest crystallised varieties, but rather in the compact slaty kinds, which often contain a considerable amount of foreign, especially earthy, matter.

The other compounds of the two oxides of iron, which are formed by the oxidation of wrought iron when heated to redness in the air, have already been noticed under the head of Protoxide.

Hydrated Magnetic Oxide of Iron. When freshly precipitated hydrate of protoxide of iron is boiled in water, hydrogen is evolved, and a hydrate of the magnetic oxide is formed. According to Lefort, two different hydrates may be obtained by pouring solutions containing both proto- and persulphate of iron into boiling potash or soda in excess. When the salts of the two oxides are to each other in the proportion of equal equivalents, we obtain 2 ($FeO + Fe^2O^3$) 3 HO, and in the second case, where the persalt is to the protosalt as 1 to 6, the resulting hydrate is of the composition $6 FeO + Fe^2O^3 + 4 HO$. Similar results may be obtained with cold solutions by the use of ammonia as a precipitant.

Magnetic Peroxide of Iron. Malaguti states that whenever carbonate or any organic salt of protoxide of iron is heated in the air until the acid is completely dissipated, a pure peroxide is obtained, which is always magnetic; and also, that when the hydrated peroxides produced by the spontaneous action of the air upon hydrated protoxide, or iron rust, which processes are always accompanied by the formation of ammonia, are calcined at a gentle heat, similar magnetic varieties of the peroxide are produced; while, on the other hand, the peroxide produced from the decomposition of a persalt is not in any degree magnetic, either before or after calcination.

The above statements are disputed by De Luca, who supposes that probably the magnetic effect is due to a small quantity of protoxide, not altered by the low heat employed, as the property is lost when the oxide is subjected to a higher temperature. Probably these contradictory views may be reconciled by assuming that peroxide of iron is under certain conditions slightly magnetic, but that the property is fugitive and may be dissipated by heat.

It is not a little remarkable that the only chemist who has succeeded in obtaining protoxide of iron should describe it as non-magnetic. Rammelsberg found the octahedral peroxide from Vesuvius, containing 15 per cent. of magnesia, to be magnetic.

There is a large class of minerals analogous in composition to magnetite, represented by the formula $RO + R^2O^3$, known as the Spinel group, in which the protoxides are those of magnesium, zinc, iron, or manganese, and the peroxides alumina and peroxide of iron. Some of these substances have been formed artificially, among them are, magnetite ($FeO. Fe^2O^3$), black spinel ($MgO. Al^2O^3$), franklinite ($ZnO. MnO. Fe^2O^3$); and magnoferrite ($MgO. Fe^2O^3$). The latter substance, artificially produced by Deville, has been described by Rammelsberg as occurring in the products of the eruption of Vesuvius in 1855.

Ferric Acid. This, the highest known oxide of iron, has the formula FeO^3, and is very similar in its properties to the corresponding oxide of manganese, MnO^3, or manganic acid. It may be formed, among other methods, by fusing finely divided iron with four times its weight of nitre, or by passing a current of chlorine through a concentrated solution of caustic potash containing peroxide of iron in suspension. In the latter method the following reaction takes place:—

$$3\,Cl + 5\,KO + Fe^2O^3 = 3\,KCl + 2\,KO.\ FeO^3;$$

the ultimate products being chloride of potassium and ferrate of potash. The latter salt, being insoluble in excess of alkali, is slowly precipitated, if the solution of potash be sufficiently strong, as a black powder, which may be dried on unglazed porcelain, but is immediately decomposed when brought into contact with filtering paper or any organic matter. It is soluble in water, giving a fine red solution, which is slowly decomposed when evaporated, even *in vacuo*, with the production of potash, peroxide of iron, and oxygen. No one has as yet succeeded in isolating ferric acid from its potash salt.

Iron and Nitrogen. The effect of nitrogen upon iron, and more especially steel, has attracted the attention of many chemists, and several elaborate memoirs have been published at different times on this subject. Unfortunately, however, the results obtained by different chemists are so contradictory, that it is impossible at present to decide with any degree of certainty as to whether nitrogen plays an important part in determining the good qualities of steel or not. All that will be attempted in this place will be to give a short analysis of the principal researches published up to the present time.

According to Fremy, when iron wire is heated to dull redness for several hours in a current of ammoniacal gas, it increases in weight from 12 to 13 per cent., and shows but little tendency to alteration when exposed to the action of the air. The nature of this change is not well understood, as it is not certain whether the product contains hydrogen or not. A similar substance is formed by acting on protochloride of iron with ammonia vapour at a red heat, the chloride being decomposed with the production of sal-ammoniac, peroxide of iron, and an amide salt, which in its turn is destroyed by the water present, forming ammonia and peroxide of iron. The residue of the operation is a fritted mass, partly fused, and often containing a greyish, brilliant, metallic-looking mass, which is nitride of iron

This substance is less oxidisable than pure iron, and may be made permanently magnetic, although less perfectly than steel. By heating in a brasqued or carbon-lined crucible, it acquires the property of hardening when plunged into water at a red heat. Although it may be heated to redness in air without change, it is immediately decomposed when heated in an atmosphere of hydrogen, ammonia and pure iron being formed. The amount of nitrogen absorbed is said to be about $9\frac{1}{2}$ per cent., which corresponds in composition to Fe^5N.

According to Savart, however, the increase in weight of iron wire exposed to the action of ammonia vapour for nine hours is only $\frac{1}{170}$ or about $\frac{1}{8}$ per cent. At the end of one or two hours the iron shows a finely granular fracture, and can be rendered sufficiently hard, by quenching in cold water, to give sparks when struck with a flint; but when the process has continued from eight to ten hours a more than ordinarily soft iron is obtained, no longer susceptible of tempering, and of a dark grey colour and graphitic appearance on a fractured surface. Dick obtained a similar small increase in weight, amounting to about $\frac{1}{250}$ when a spiral iron wire was heated to redness in a current of ammonia for one hour and a quarter, and only $\frac{1}{600}$ when a straight and thicker wire—that is, one presenting less surface—was substituted.

Bouis and Boussingault have determined the amount of nitrogen contained in various kinds of commercial iron, as well as in an artificial nitride prepared by Despretz; the latter contained about $2\frac{2}{3}$ per cent., while in the former the nitrogen varied from $\frac{1}{13}$ to $\frac{1}{4}$ per cent.

Iron and Phosphorus. Iron may be made to combine with phosphorus at a red heat, either directly or during the reduction of an oxide of iron in the presence of an earthy phosphate and carbon, the latter condition being of very common occurrence in metallurgical practice. Percy, in a systematic account of the phosphides of iron, describes no less than seven, as follows:—

1. $Fe^{12}P$.	Formed by	dropping phosphorus on to red-hot iron.
2. $Fe^{6}P$.	„	heating $Fe^{2}P$.
3. $Fe^{4}P$.	„	reducing protophosphate of iron with carbon.
4. $Fe^{2}P$.	„	exposing iron reduced by hydrogen to phosphorus vapour at a low temperature.
5. $Fe^{8}P^{3}$.	„	reducing sesquiphosphate of iron with hydrogen at a white heat.
6. $Fe^{5}P^{2}$.	„	acting on phosphuretted copper and iron with nitric acid.
7. $Fe^{3}P^{2}$.	„	passing phosphuretted hydrogen over iron pyrites at a low heat.

The composition and properties of the combinations of iron and phosphorus have been reinvestigated by Freese, who has arrived at results (*Poggendorf, Annalzen,* vol. cxxxii., p. 225) differing in some particulars from those obtained by former observers. The method principally adopted for the formation of the phosphides, consisted in heating metallic iron or its compounds in a current of phosphuretted hydrogen, produced by the action of caustic potash lye upon amorphous phosphorus; the gas so obtained not being subject to spontaneous ignition when brought in contact with the air. Berzelius's method of fusing phosphate of iron with carbon was also employed. Freese states that only three definite compounds can be obtained by these means; they have the following atomic and percentage compositions:—

	Sp. gr.	Phosphorus.	Iron.
I. Fe^3P_2.	5·04	57·53	52·47
II. Fe^2P.	5·21	42·47	57·53
III. Fe^4P.	5·74	21.68	78.32

The first of the above compounds is produced by the action of phosphoretted hydrogen at a red heat upon iron reduced by hydrogen; it is described as a dark bluish-grey non-magnetic powder, infusible and unalterable in the air at ordinary temperatures, but burning, when heated, with an evolution of phosphorus, whereby it becomes reduced to the compound Fe^2P. It may also be formed from anhydrous protochloride of iron, or magnetic pyrites, as well as from metallic iron. The phosphide Fe^2P is formed by heating protosulphide of iron, FeS, in phosphuretted hydrogen; it is generally similar to the former one, but is somewhat lighter in colour. When heated it burns, but without giving off phosphorus, and the resulting phosphate contains both oxides of iron. The most basic of the three phosphides, Fe^4P, is formed by exposing a mixture of 3½ parts of phosphate of iron and 1 of lamp-black, under a covering of common salt, in a crucible to a white heat for four hours. The fused mass is afterwards treated with weak hydrochloric acid, in order to remove the salt and the excess of undecomposed phosphate, the quantity of carbon employed being insufficient to reduce the whole of the latter salt, so as to prevent the formation of carburized iron. The residue of this operation is light a grey crystalline powder, which is non-magnetic, and in other respects very like the higher phosphides previously described.

When heated in hydrogen, carbonic oxide, or carbonic acid, none of the phosphides of iron show any sign of fusibility; but in air they are more or less completely oxidized with the formation of phosphates. With the higher ones, this change is only superficial, the crust of phosphate protecting the powder underneath from further action; but the lower form, Fe^4P, is completely altered, and fuses to a dark crystalline mass, having a metallic lustre. The fusibility usually attributed to the last-mentioned phosphide is, according to Freese, due to its containing iron and carbon as impurities.

When any phosphide of iron is heated with hydrochloric acid it is very slowly, but entirely, decomposed, the phosphorus being partly evolved as phosphoretted hydrogen, and partly oxidized to phosphoric acid, the proportion of the former to the latter being as 5 to 3; the oxygen and hydrogen in the two compounds standing in the same atomic relation to each other, as they do in water.

Phosphate of Iron. Of the numerous class of salts formed by the oxides of iron and phosphoric acid, only one is of any great interest, namely, the natural mineral known as *Vivianite*, a product of alteration by partial oxidation of the tribasic phosphate of the protoxide, its composition being represented by the somewhat complex formula, $6\ (3\ FeO.\ PO^5) + (3\ Fe^2O^3.\ 2\ PO^5) + 8\ HO$. It is very commonly formed in wet ground from decaying animal or vegetable matter containing phosphates, such as hard wood, or more especially bones and teeth of animals, when brought in contact with water containing a protosalt of iron in solution. Beech-trees growing in soils containing iron pyrites, which by decomposition yield protosulphate of iron, often deposit vivianite in their stems and roots while still living, from the absorption of the sulphate which is decomposed by the phosphate of lime present in the plant, with the production of insoluble phosphate of iron in the cells of the trunk. The wood becomes very hard by this addition, and when the tree is cut down the surface of the stump gradually assumes a greenish-blue colour by the absorption of oxygen from the air. The same mineral is also common in the bones and teeth of animals that have become imbedded in peat bogs, either as a dull blue incrustation or occasionally in small acicular crystals in the cavities, and occurs at times in the organic remains contained in impervious clays. An example of this is furnished by the fossils contained in the Oxford clay in Buckinghamshire, where the shells have at times entirely disappeared, leaving only a hollow cast in the stiff clay, the cavity being often lined with small tufts of vivianite and gypsum, derived from the mutual reaction of the products of decomposition of the soft parts of the animal and the mineral matter of the shell.

Phosphorus is one of the most unwelcome ingredients in iron ores, from the ease with which it passes into the metal during the smelting process, producing the most injurious effects if present in more than a very small proportion.

Wrought iron containing not more than $\frac{3}{10}$ per cent. of phosphorus, is not sensibly affected in tenacity, but is only rendered somewhat harder; with $\frac{1}{2}$ per cent. it becomes somewhat *cold short*, or incapable of being wrought cold under the hammer without breaking; with $\frac{8}{10}$ per cent. the cold shortness is very decided; and 1 per cent. makes the metal very brittle.

The tenacity of cast iron is also sensibly diminished by phosphorus, so that the metal made from the worst kinds of bog ores cannot be employed for castings requiring great strength; but this is counterbalanced by the properties of acquiring great fluidity, and taking good impressions, which render it proper to be used for small and intricate ornamental castings.

Arsenic and *Iron* readily unite, forming compounds which may be subjected to a high degree of heat without decomposition. These compounds are usually known by the German term, *Speiss*, and are of common occurrence in the smelting of arsenical silver and lead ores when the reduction of the sulphide of lead is effected by iron. They are found in thin layers of a columnar crystalline structure between the reduced lead and the supernatant regulus of copper and other sulphides when the molten contents of the furnace are allowed to settle in a basin after tapping. The ordinary composition of such a speiss is represented by the formula $Fe^6As.$; when nickel or cobalt is present in the ore it invariably passes into it.

Although arsenic and iron are found in combination in a great variety of minerals both as arsenides and arseniates, yet, as none of them are used as iron ores, nor do they as a rule occur in any quantity as accidental admixture with such ores, it is rarely that arsenic is found as an impurity in the metal. Two instances are, however, recorded of its presence in considerable amount in cast iron, both being in shot and shell of Turkish origin, those brought from Sinope containing 16·2 per cent., while of others found in the arsenal at Algiers on the French occupation in 1830, the shells contained 9 and the shot 27 per cent. Such metal is very brittle, white, with a brilliant radiated structure, and unfit for conversion into malleable iron by the puddling process, as it yields bars which are *red short*, or brittle at a red heat, although sufficiently tenacious to bear hammering when cold. A smaller amount of arsenic is, however, said to be beneficial when the metal is intended for chill casting; that is, for castings whose surfaces are artificially hardened by the use of cold metal moulds.

Sulphur and Iron. The compounds of sulphur and iron are of considerable importance to the iron smelter, as they are commonly present as impurities in many iron ores, and impart the defect of red shortness to the metal, even when only a very small proportion of sulphur is taken. The protosulphide, FeS., corresponding in composition to the protoxide, is not found in nature, but may be readily formed by dropping sulphur on to heated scrap iron, or in the wet way by adding an alkaline sulphide to the solution of any protosalt of iron. When produced by the first method, it melts easily to a dark bronzy-black mass, with a metallic lustre, which combines readily with the sulphides of other metals, a property which is largely utilised in the smelting of copper and silver ores; the so-called *matte*, *coarse metal*, or *regulus*, is an example, being a sulphide of iron containing more or less of the sulphides of the valuable metals, which is obtained in the first fusion, whereby the earthy matters in the ore are eliminated, and the metallic contents concentrated for further treatment.

The protosulphide is but slightly affected when heated with ordinary reducing agents, such as carbon, or even hydrogen, but may be almost completely decomposed at a high temperature by oxidising substances, such as peroxide of iron or silica, or by the action of air at a red heat, the change in the latter case being accompanied by the formation of various sulphates of both protoxide and peroxide; the ultimate product, however, being pure peroxide of iron.

The persulphide Fe^2S^3 may be formed artificially, but does not occur in nature in a free state, although it is found in combination with the sulphides of other metals, more especially those of copper.

Magnetic Pyrites, or *Pyrrhotine*, $6\,FeS + FeS^2$, the most basic of the native sulphides of iron, is a bright bronze-coloured mineral, crystallising in the rhombohedral system, and remarkable for its magnetic properties, which are, however, feebler than those of the magnetic oxide. It is occasionally found in association with iron ores, but more generally with those of copper and nickel, as well as with native gold, being more especially confined to crystalline rocks.

Bisulphide of Iron, FeS^2. This is the well-known substance which, under the name of iron pyrites, is found in greater or less quantity in every member of the geological series. Two principal varieties are distinguishable, namely, ordinary iron pyrites, which is of a brassy-yellow colour, crystallising in the cubical system, and marcasite, or white iron pyrites, a rhombic mineral, of a lighter colour, softer, and more readily decomposed than the cubical kind. The percentage composition is, iron 48, sulphur 52.

When heated in close vessels, iron pyrites is decomposed with partial separation of sulphur, which sublimes, leaving a residue of proto- or perhaps magnetic sulphide. If, however, the operation is conducted with a free access of air, the sulphur burns to sulphurous acid, causing a great increase of temperature, and is ultimately wholly expelled, leaving peroxide of iron behind, which, if the pyrites employed be sufficiently pure, may be used as an iron ore. The residues obtained from pyrites in sulphuric acid manufacture are so employed in Cleveland, under the name of *Blue Billy*. When exposed to moist air, iron pyrites, especially the rhombic variety, is rapidly changed to protosulphate of iron, and conversely, when the latter salt is brought into contact with decomposing organic matter in situations where air is excluded, pyrites is formed. It is probably in this way that the greater part of the pyrites existing in sedimentary rocks has been formed.

Sulphate of Protoxide of Iron. This salt, well known by its commercial names of *green vitriol* or *copperas*, crystallises in the oblique system, forming pale green crystals having the composition $FeO. SO^3 + 7 HO$. Like most other salts of the same base, it is very susceptible of oxidation, changing colour in the air even when crystallised, but more rapidly when in solution, by the absorption of oxygen and the formation of partly soluble and partly insoluble sulphates of the peroxide. These are very complex in composition, and are described at length in the larger chemical text-books. Among them are several minerals, such as coquimbite, copiapite, misy, and others.

Iron and Chlorine. There are two chlorides of iron, corresponding in composition to the two lower oxides, or protochloride, $FeCl$, and perchloride, Fe^2Cl^3. The former is produced when metallic iron is dissolved in hydrochloric acid, and may be obtained in a hydrated form by concentrating the solution, when green crystals are deposited. These are doubly oblique in form, and have the composition $FeCl + 4\ HO$.

When hydrochloric acid gas is passed over iron wire heated to redness, anhydrous protochloride is formed, and condenses in the cooler portion of the tube in colourless cubical crystals. The hydrated perchloride may be prepared by boiling the protochloride with nitric acid, by dissolving peroxide of iron in hydrochloric acid, or by the action of aqua regia on metallic iron. The solution obtained by either of the above methods yields on evaporation, rhombohedral crystals, whose composition is $Fe^2Cl^3 + 6\ HO$.

The anhydrous perchloride is formed when dry chlorine is passed in considerable quantity through a porcelain tube containing iron wire heated to redness. It crystallises in hexagonal scales, which deliquesce in moist air.

When magnetic or other mixed ores, containing both per- and protoxide of iron, are dissolved in hydrochloric acid, both chlorides are formed in the solution, in the same proportion to each other as that of the two oxides in the substance operated upon. This property is of great value to the analytical chemist, as by it he is enabled to determine, in many cases, the state of oxidation in which iron exists in the ore.

Iron and Silicon. According to Percy, iron does not combine with silicon when heated with silica unless carbon be present. Under the latter condition, however, by reducing an intimate mixture o peroxide of iron and sand with charcoal in a wind furnace, a variety of cast iron may be obtained containing as much as 13 per cent. of silicon, which is very hard and brittle. By effecting the reduction at the high temperature of a Siemens steel furnace, Riley has obtained cast iron with 21 per cent. of silicon. It is highly crystalline, and silvery white in colour

Protosilicate of Iron. Protoxide of iron combines readily with silica at the welding temperature of the metal. Familiar examples of this property are furnished by the use of sand in the smith's forge to remove the scale formed during the heating of the iron, and also by the so-called forge and mill cinders produced in the welding of malleable iron by the puddling and reheating processes.

The whole of the above substances are essentially tribasic silicates of protoxide of iron, represented by the formula $3\,FeO.\,SiO^3$, containing 70 per cent. of protoxide of iron, and 30 per cent. of silica, which melts at a white heat, becoming very liquid, and crystallising on cooling.

When formed under favourable conditions the crystals are often very perfect modified rhombic prisms, analogous in form to those of *olivine,* a silicate of magnesia having a similar atomic constitution, which occurs largely in volcanic rocks, and also in meteoric stones.

When heated with access of air, protosilicate of iron, such as the slag of the puddling furnace, is decomposed, the iron passes in great part into the state of peroxide, and separates from the silica, giving a substance which, under the name of "bull-dog," is largely used for lining the hearths of puddling furnaces. The refractory nature of this product is due to the infusible character of the two oxides, and their inability to unite and fuse together when exposed to an oxidising atmosphere.

By reference to the percentage composition given above it will be seen that silica requires 2⅓ times its own weight of protoxide of iron to form a slag, or, what is the same thing, one part by weight of silicon takes up rather more than 3¾ parts of metallic iron. These figures indicate the great loss of iron which takes place in the refining of pig iron rich in silicon.

The iron contained in puddling-furnace cinder and other slags of a similar character may be reproduced by treating them in the blast furnace, either alone, or, what is preferable, in admixture with the ordinary charges of ore and flux. As, however, nearly the whole of the phosphorus contained in the original ore is passed into the slags during the process of puddling, the metal produced from them is necessarily of very inferior quality. The term *cinder pig* is applied to this kind of iron, in contradistinction to *mine pig*, which is smelted from ores alone.

Richardson found that when pure tribasic protosilicate of iron was heated with carbon, two-thirds of the iron was reduced to the malleable form, leaving a slag of the composition $FeO.\ SiO^3$.

Silicon renders malleable iron hard and brittle. Owing to the ease, however, with which this element can be removed in the manufacture, it is rarely present in quantity sufficient to exert a marked influence. On cast iron its effect is very similar to that of carbon, and as both are of common occurrence in, and exert an important joint influence on, pig iron, it will be more convenient to consider this point subsequently.

Iron and Carbon. Combination between iron and carbon may be readily effected in several different ways, either by the direct action of carbonaceous fuel, or more properly carbonic oxide gas, at a high temperature, as takes place in the reduction of ores by the blast furnace, or by maintaining the metal in a compact state, such as ordinary bar iron, for a lengthened period at a lower temperature in contact with charcoal, compounds containing cyanogen, or the vapour of hydrocarbons. The latter process, called *cementation*, is applied on a large scale in the manufacture of steel.

As has been already stated in the introductory paragraphs, the iron of commerce is divided into wrought iron, steel, or cast iron, according to the amount of carbon taken up, the proportion in the different varieties being, according to Karsten, as follows:—

Name.	Percentage of Carbon.	Properties.
1. Malleable iron	0·25	Is not sensibly hardened by sudden cooling.
2. Steely iron .	0·35	Can be slightly hardened by quenching.
3. Steel . . .	0·50	Gives sparks with a flint when hardened.
4. do. . . .	1·00 to 1·50	Limits for steel of maximum hardness and tenacity.
5. do. . . .	1·75	Superior limit of welding steel.
6. do. . . .	1·80	Very hard cast steel, forging with great difficulty.
7. do. . . .	1·90	Not malleable hot.
8. Cast iron . .	2·00	Lower limits of cast iron cannot be hammered.
9. do. . . .	6·00	Highest carburetted compound obtainable.

Condition of Carbon in Iron. Carbon may be contained in cast iron either in chemical combination, or diffused through the mass in the form of crystals of graphite which have separated from the molten metal in cooling. The latter variety is known as *grey*, and the former as *white*, cast iron.

When grey cast iron is dissolved in an acid, its graphitic carbon remains unaltered in the insoluble residue; but when the white variety is similarly treated, only a small portion of the carbon separates, the combined portion uniting with the hydrogen evolved from the water decomposed during the solution of the metal, and forming hydrocarbons which are partly liquid and partly volatile: the latter have a very fetid smell.

By sudden cooling, as in the process of chill casting, grey cast iron may be rendered white: the effect is usually only superficial, the interior still retaining its greyness.

According to Caron, the state in which carbon exists in steel depends upon the treatment to which the metal has been subjected. The softer qualities contain it as graphite, which is liable to pass into combination by hardening or hammering; by annealing, the graphitic character is restored. It would appear from this that chill casting and the hardening of steel are probably due to the passage of carbon from the free to the combined state.

Much has been written at different times by numerous observers on the probable atomic composition of the carbides of iron, but great diversity of opinion still prevails on this point. Karsten supposed *Spiegeleisen*, or specular pig iron, the most highly carbonised and crystalline white metal, to be a carbide of the composition Fe^4C, which would contain 5·08 per cent. of carbon. Dick, however, was unable to obtain white iron by reducing perfectly pure sesquioxide of iron with an excess of pure carbon at the highest temperature of an assay furnace, the result being a grey button of metal containing about 4⅓ per cent. of uncombined carbon. As Spiegeleisen, however, contains a notable quantity of manganese, it is probably the latter metal that influences the combination of the carbon, and that the carbide, if it exist at all, may be represented as $(FeMn)^4C$, but its existence has not as yet been determined by experiment.

Rammelsberg states that Karsten's formula for Spiegeleisen cannot be established, even supposing the carbon to be partly replaced by silicon, as the largest quantity of the latter element is found in the most highly carburetted varieties; thus, Müsen Spiegeleisen contained 0·5 of silicon, that of Mägdesprung 0·17 per cent., and Styrian, with only from 3·75 to 4·14 per cent. of carbon, but 0·01 to 0·027 per cent.

Gurlt has endeavoured to establish the existence of a lower carbide corresponding to the formula Fe^8C, which he supposed to stand in the same relation to grey, that Karsten's tetracarbide, Fe^4C, does to white cast iron. This compound was supposed to have been found at Gleiwitz, in Silesia, crystallised in octahedra in the hollows of unsound castings made of dark grey iron, which on analysis yielded—

Carbon combined	2·46
,, graphitic	2·84
Silicon	0·26
Iron	94·20
	99·76

The formula deduced from this is $Fe^8(C.Si)$, the silicon taking the place of a portion of the carbon.

Rammelsberg, on the other hand, states that these and similar crystals from other localities are probably only metallic (malleable) iron, containing variable amounts of impurities, such as carbon, silicon, phosphorus, and sulphur, and that their composition cannot be expressed by Gurlt's formula unless all these foreign matters are supposed to replace a portion of the carbon.

Kalle mentions a fact observed by Richter at the Prussian ordnance foundry at Spandau, which appears to confirm Rammelsberg's opinion. When dark grey iron was melted and exposed to the highest heat attainable in a reverberatory furnace, the amount of combined carbon was reduced to 0·12 per cent. out of a total of 3 per cent. Guns cast from this over-heated metal, which failed on proof, were found to be sensibly bulged near the muzzle, and in one instance the bore increased gradually, indicating a decided softness. Kalle therefore supposes that such metal may be considered as a mixture of malleable iron and graphite, the almost entire separation of the combined carbon being due to the excessive heating.

Graphitic carbon is found to a small extent in white iron, as is seen in the following analyses by Bromeis of cast iron from Mägdesprung, in the Harz.

Name.	Combined Carbon.	Graphitic Carbon.	Total.
	Per Cent.	Per Cent.	Per Cent.
1. Bright white iron . .	2·518	0·500	3·018
2. White forge pig . .	2·908	0·500	3·458
3. Spiegeleisen . . .	3·100	0·720	3·820

Dark grey cast iron, in addition to uncombined carbon, often contains silicon in the same state, the latter element being capable of assuming a graphitic character. It occurs more particularly in the products of hot blast furnaces working in difficultly reducible ores.

Very white iron, on the other hand, such as Spiegeleisen, can only be produced from easily reducible ores, especially those containing manganese.

When sulphur to the extent of about 2½ per cent. is melted with grey cast iron, a portion of the carbon separates in a sooty form, and an intensely hard white metal is produced. With a smaller quantity of from ⅓ to ½ per cent. a mottled iron of great strength is obtained, which, when broken, shows a quantity of grey spots, enclosed by reticulating lines of white, on the fractured surface. The well-known Swedish gun-foundry iron is of this character, a small portion of sulphur being introduced by the use of an ore containing a little iron pyrites, and admixture with the ordinary charge of the blast furnace.

The method of imparting carbon to malleable iron so as to form compounds less highly carburetted than cast iron, by exposing it, at a temperature below its melting point, to the long-continued action of charcoal, is called *cementation,* and the product of the operation is known as cement or *blister* steel. A similar effect is produced more rapidly when the iron is heated in coal gas, or the vapour of a volatile hydrocarbon, such as paraffine, instead of charcoal. The superficial cementation of wrought iron by heating it for a short time in contact with carbonised leather or cyanogen compounds is termed *case hardening.*

The exact cause of the change effected in bar iron by cementation has not been conclusively determined, and has recently been the subject of a long-continued controversy between two French chemists, Messrs. Fremy and Caron, in the proceedings of the Academy of Sciences at Paris, the essential point in dispute being the necessity or otherwise of nitrogen for the production of steel. Fremy considers that cast iron and steel are not simply compounds of iron and carbon, but that the presence of other elements is necessary, such as sulphur, phosphorus, silicon, arsenic, and nitrogen, but more especially the latter. The following extraordinary analysis, said to be of a first class razor blade made from Dannemora iron, is quoted in support of this view:—

	I.	II.
Carbon	1·43	0·087
Sulphur	1·00	0·220
Silicon	0·52	0·115
Antimony	0·12	—
Arsenic	0·93	trace
Phosphorus	—	0·034
Nickel	0·18	—
Manganese	1·92	—
Iron	93·80	99·544
	99·90	100·00

Analysis II. of Dannemora iron by Henry is sufficient to show that the steel in question could not have been produced by the ordinary processes of steel manufacture.

The general classification of commercial iron according to Fremy's hypothesis is as follows:—

1. Wrought iron is more or less pure iron, the softest kinds being the purest.
2. Cast iron is iron combined with more or less of carbon, part of which may be replaced by silicon.
3. Steel is a ternary compound of iron, carbon. and nitrogen, or nitro-carburetted iron.

Caron, on the other hand, while admitting the value of nitrogen in facilitating the conversion of malleable iron into steel, is not disposed to consider it as an essential ingredient on account of the very small amount that can be discovered in steel by analysis.

The contradictory results obtained by different chemists who have attempted to form nitrides of iron have already been noticed at p. 28.

Dick found that electrotype iron was more readily converted into steel by cementation in an atmosphere of hydrogen than the best sheet iron, a fact that bears heavily against Fremy's view, as the metal was remarkable for softness and purity, and was free from nitrogen.

Marguerite, in a recent article, states that steel is formed when iron is heated with diamond dust in hydrogen, or alone in carbonic oxide. In the latter case carbon separates from the gas and is taken up by the metal, and carbonic acid is produced. When silicon is present it is oxidised to silica at the expense of the carbonic oxide, also with a separation of carbon.

A new theory of cementation has recently been propounded by Graham, founded upon the property possessed by iron of dissolving carbonic oxide at low temperatures.

As the case stands at present, the weight of evidence is certainly against the necessity of the existence of nitrogen in steel, and it is most likely that the older view of Karsten, that its essential qualities are due to variations in the amount of carbon, is in the main correct, although they may be modified by the presence of other elements.

From what has been previously advanced as to the composition of cast iron, the following propositions may be deduced:—

1. The greater part of the carbon is in white cast

iron chemically combined, and in grey diffused as graphite.

2. Neither variety is, however, entirely free from graphitic or combined carbon respectively.

3. Although containing carbon in chemical combination, there is no certain evidence of the existence of any defined carbide in white iron, but Spiegeleisen may possibly be a double carbide of iron and manganese.

4. Dark grey iron is not a lower carbide of iron than Spiegeleisen, but is probably only a mixture of malleable iron and graphite, and its chemically combined carbon may be reduced to a minimum by intense heating when melted.

5. Silicon is a common constituent of grey cast iron.

6. Chill casting, and the addition of sulphur, tend to produce whiteness in grey cast iron, and a similar change may be effected in steel by hardening or forging.

The combination of mechanical with chemical analysis has been recently applied to the investigation of the composition of cast iron by Mr. G. J. Snelus, of Dowlais. He found that when very grey pig iron was reduced to a coarse powder in a steel mortar, scales of graphite were removed from the crystalline facets of the iron, and these, when subjected to combustion, were entirely converted into carbonic acid without leaving any residue, proving them to be even purer than natural graphite. A large proportion of the graphitic carbon can also be separated when borings of grey pig iron are sifted through fine silk gauze, or levigated with water; the finer and lighter portions in each instance retaining the largest amount of carbon, as shown in the following percentage determinations.

	Original Carbon.		Fine Siftings.	Light Washings.
1. Bessemer pig . .	Graphitic . .	3·34	9·11	28·41
	Combined . .	—	—	—
2. " " . .	Graphitic . .	3·19	7·79	21·27
	Combined . .	0·20	0·17	—
3. Cleveland forge pig .	Graphitic . .	2·65	7·02	41·33
	Combined . .	0·35	0·30	—

These results show clearly that in grey pig iron the free or graphitic carbon can be more or less perfectly separated by mechanical means, while the combined carbon decreases in the same ratio as the residual iron. On the other hand, no separation of silicon could be effected by this method; for instead of increasing in the finer and lighter portions, as the graphite does, it actually decreases with the increase of the latter, thus proving that even in the most highly siliciferous pigs the whole of the silicon is in the state of combination.

Of the influence of other Metals on Iron, Alloys of Iron. Iron alloys with great difficulty with the commoner heavy metals, but more readily with gold, and those of the platinum group. None of these alloys have as yet been economically applied to any extent. The following remarks are chiefly from Guettier:—

Copper and *Iron* may be melted together in almost all proportions, but it appears to be doubtful whether any homogeneous alloys can be produced. A small quantity of iron added to bronze or brass causes a considerable increase in tenacity. Malleable iron or steel containing copper to the extent of 0·45 or 0·5 per cent. shows symptoms of red shortness, which become decided with a larger quantity.

Zinc and *Iron* do not form any useful alloy; about

7 per cent. of the latter metal may be taken up when zinc is kept melted in cast-iron pots, or when its vapour is passed through wrought-iron tubes. The former condition prevails in the process called *galvanising*, or the zincing of sheet iron by immersion in melted zinc. The cast-iron pots used for holding the molten metal, where exposed to the greatest heat, are slowly corroded with the formation of an alloy which does not differ much in appearance from metallic zinc. The formation of this substance is a source of considerable loss in the manufacture, but may be prevented by filling the pot to a certain height with melted lead, upon which the zinc floats, and only comes in contact with iron at a temperature below that necessary for combination.

Tin and Iron. These metals unite in almost every proportion, but their alloys are not employed as such in the arts. When applied in a similar manner, however, to zinc in the galvanising process—that is, when sheet iron is immersed in a bath of melted tin—the well-known *tin-plate* is produced. An inferior variety, coated with an alloy of tin and lead, is called *terne-plate*. Malleable iron containing 0·5 per cent. of tin is hard, but cannot be hammered cold, and welds with difficulty. Cast iron with about 5 per cent. of tin is hard, and breaks with a fine steely fracture: it has been tried as an alloy for casting bells. Tin with 2 per cent. of iron is magnetic, sensibly duller in lustre than the pure metal, and hard and short in fracture.

An alloy of 10 parts of iron with 60 or 80 of tin is recommended for use in tinning copper utensils, in preference to pure tin.

Iron and lead cannot be made to unite with each other by fusion.

Antimony, when present in very small quantity, from 0·1 to 0·3 per cent., acts very injuriously upon malleable iron, rendering it in the highest degree both hot and cold short. The so-called *martial regulus*, containing 7 parts of antimony to 1 of iron, is recommended for producing casts of medallions and other relief impressions in preference to cast iron.

Nickel alloys readily with iron without affecting its malleability; this is exemplified in meteoric iron masses, which contain a considerable quantity of the former metal, and have occasionally been used for the manufacture of knives by savages. A horse-shoe made from the great Australian meteorite was exhibited at Kensington in 1862, and is now in the Museum of Practical Geology. The mass from which it was taken, weighing 3½ tons, has been given to the British Museum.

Cobalt is said to increase the whiteness and brilliancy of iron, but has no marked effect upon its physical properties. *Chromium* acts in a similar manner, but also communicates hardness and brittleness. Steel containing 1·2 per cent. of chromium gives a beautiful damask surface when etched by sulphuric acid.

Silver and iron do not alloy, a separation of the two metals being apparent when steel is melted with as little as 0·5 per cent. of silver. It is different, however, with gold, which is readily taken up under similar conditions. This property was formerly applied in the treatment of auriferous sands in Russia; the concentrated black sand from the first washing, consisting principally of magnetic iron ore and gold, having been smelted with charcoal in small blast furnaces for pig iron, from which the gold was afterwards extracted by the action of sulphuric acid

Faraday and Stodart found that platinum alloyed readily with steel, and produced a very tough and fine-grained product when present to the extent of 1 per cent. Similar results were obtained with the other metals of the same group, palladium, rhodium, and osmiridium. As, however, these metals are rare and high priced, it is not probable that these alloys could be introduced on a practical scale.

Tungsten has the property of rendering cast steel very hard and tenacious. According to Bernouilli, when an intimate mixture of finely divided grey cast iron and tungstic acid is heated to a very high temperature, the graphitic carbon is burnt by the oxygen of the tungstic acid, and steel is formed, which alloys with the reduced tungsten. No diminution in the amount of carbon was, however, perceived when the experiment was repeated with Spiegeleisen, or ordinary white cast iron, carbon in the combined form being apparently unable to effect the reduction of the tungstic acid. Siewert examined six samples of so-called tungsten steel: four of them contained from 1 to 3 per cent. of tungsten, while none was found in the other two.

Vanadium was found in minute quantities by Sefström in iron made from the magnetic ore of Taberg, in Sweden, which is noted for its yielding a first-rate iron for wire-drawing. More recently Riley has detected the same substance in pig iron made from oolitic brown hematite at Westbury, in Wiltshire. It has also been found in different varieties of oolitic iron ores in other places, such as the *Bohnerz*, or pisolitic ore, of South-Western Germany, and the Cleveland ores.

The iron made from these ores in the Bernese Jura contains an appreciable quantity of vanadium, and is also in repute for wire-drawing, having been specially selected for use in the great wire bridges at Fribourg, in Switzerland.

Titanium may be present in pig iron to the extent of about 1 per cent. when a proportion of titaniferous ore is added to the charge. It increases the strength of the metal, at the same time giving it a peculiar mottled character, the fractured surface showing a series of dull dark grey patches set in a white network. It is doubtful whether any portion of the titanium is retained in the bar iron or steel made from such pig iron, so that the improvement attributed to the use of titaniferous ore is probably due to some indirect action rather than to the actual presence of titanium in the finished product. The evidence on this point is not sufficiently clear to allow of any positive conclusion being formed. Ores containing more than 8 per cent. of titanic acid are very refractory, and difficult to smelt.

CHAPTER III.

COMPOSITION AND DISTRIBUTION OF IRON ORES.

AMONG the numerous minerals containing iron, only the oxides and carbonates can be used by the smelter. They are as follows:—

1. *Magnetic Iron Ore*, or *Magnetite*, crystallises in the cubical system, usually in octahedra or rhombic dodecahedrons, but more generally massive, varying in texture in the fracture from coarsely crystalline to finely granular, or even massive. Colour black, with occasionally a slight greenish or brown cast. Streak black. Magnetic, and sometimes polar. Specific gravity 5·2.

Composition, $FeO + Fe^2O^3$, containing 72·41 per cent. of iron.

2. *Franklinite.* Cubical, crystallising in octahedra; also massive; very similar in colour and general appearance to magnetite, but less magnetic, and gives a dark reddish-brown streak. Specific gravity, 5·1. Composition, $3 (FeO. ZnO. MnO) + (Fe^2O^3. Mn^2O^3)$. The average of several analyses by Rammelsberg gives—

Iron	45·16
Manganese	9·38
Zinc	20·30
Oxygen	25·16
	100·00

It is a rare substance, being found only at two or three localities in New Jersey, where it occurs in metamorphic Silurian limestone as a bed from 20 to 30 feet thick, overlaid by from 6 to 8 feet of red zinc ore. Both minerals are first treated for zinc, and the residues are then smelted for Spiegeleisen.

3. *Hematite.* Rhombohedral, crystallising usually in highly modified rhombohedral or scalenohedral forms; combines with the terminal plane of the prism; the latter, by its prominence, usually giving a tabular form to the crystals. Also in fibrous, columnar, botryoidal, granular, pisolitic, and compact forms. Colour varies from brilliant bluish grey in the crystallised, to a deep red in the compact, varieties; the streak is red in all cases. Specific gravity, 5·3 for crystallised, down to 4·2 in some earthy varieties. Sometimes very slightly magnetic. Composition, Fe^2O^3, with 70 per cent. of iron. Special names are given to the different varieties as follows:—

Specular Iron Ore, Oligiste, or *Iron Glance*, includes the brilliant, hard, well-crystallised forms, such as those of Elba, Brazil, Vesuvius, &c.

Micaceous Iron Ore includes all the scaly crystalline varieties, such as those of South Devon, which are loosely coherent, and similar to graphite in structure.

Kidney Ore, or *Rother Glaskopf*, includes the hard botryoidal forms, such as those of Cumberland, which are devoid of metallic lustre.

Red Ochre and *Iron Minium* are compact earthy varieties, often containing clay, which are ground and used as colours.

Puddler's Ore is a peculiar, unctuous, compact form, from Cumberland, which is largely used for lining the hearths of puddling furnaces.

The term, *Red Hematite*, is commonly used by English iron-smelters for all minerals consisting essentially of anhydrous peroxide of iron.

Ilmenite, or *Titaniferous Iron Ore*. Rhombohedral, the crystals being similar in general appearance to those of hematite; they are, however, rare, the mineral being usually found massive. Colour dead black, with a brownish streak; fracture conchoidal. Specific gravity, from 4·5 to 5. Contains proto- and peroxide of iron, titanic acid, and magnesia in very variable proportions. The following types of composition have been established by Rammelsberg:—

I. $\mathrm{FeO.\ TiO^2}$, containing 52·63 titanic acid, and 47·37 protoxide of iron.

II. $\mathrm{FeO.\ TiO^2 + MgO.\ TiO^2}$, containing 58·82 titanic acid, 26·47 protoxide of iron, and 14·71 magnesia.

III. $m\mathrm{FeO.\ TiO^2} + n\mathrm{Fe^2O^3}$, or isomorphous mixtures of titanate of protoxide of iron with peroxide in indefinite proportions, the observed limits being—

$$9\ FeO.\ TiO^2 + Fe^2O^3 \text{ and}$$
$$FeO.\ TiO^2 + 13\ Fe^2O^3.$$

the former containing 47·12 and the latter only 3·55 per cent. of titanic acid. Magnesia appears to be very generally present.

Göthite. This includes all the crystallised varieties of hydrated peroxide of iron. The primary form is a rhombic prism, but the crystals are often fibrous or scaly. Specific gravity, 4 to 4·4. Colour varies from rust-yellow to a rich reddish brown, or more rarely nearly black. The surfaces of fibrous aggregates often have a peculiar velvety lustre. Streak brown. Composition, $Fe^2O^3 + HO$, or monohydrated sesquioxide of iron, with 90·5 per cent. of peroxide, or 63·0 per cent. of metallic iron, and 10·5 per cent. of water. Lepidocrocite and Stilpnosiderite are particular fibrous and scaly varieties of the same mineral.

Brown Iron Ore. This term is used to designate the compact and earthy minerals that consist essentially of three equivalents of water united to two of peroxide of iron, or $2\ Fe^2O^3 + 3\ HO$; the percentage composition, corresponding to the formula, being—peroxide of iron 85·6 (metallic iron 59·9), and water 14·4. They are mostly dull in lustre, varying in colour from light umber brown to nearly black. Specific gravity, 3·6 to 4. Streak yellowish brown.

Both hydrates of peroxide of iron are usually included in the smelter's term *brown hematite*, signifying minerals which, although resembling hematite proper in outward appearance, can readily be distinguished by their brown streak. In Staffordshire, the term *hydrate of iron* is sometimes used. Bog iron ores, and those deposited in the beds of lakes by infusorial action, belong to the same class.

Siderite. This is the mineralogical name of carbonate of protoxide of iron, which crystallises in the rhombohedral system. The commonest forms are rhombohedra; hexagonal prisms, and scalenohedra, being less frequent. In a massive form, it occurs in isolated nodules, or occasionally in connected beds. Specific gravity, 3·7 to 3·9. Lustre of crystals pearly; colour usually some shades of yellowish brown or grey, owing to the formation of a superficial coating of hydrated peroxide; the streak is white, representing the true colour of the unaltered mineral. Composition, $FeO. CO^2$, with 62·07 per cent. of protoxide of iron (48·22 metallic iron), and 37·93 per cent. of carbonic acid. A portion of the base is, however, almost invariably replaced by protoxide of manganese, lime, or magnesia, the former oxide varying in quantity from 0 to 59 per cent. in different varieties.

The purer crystalline varieties are called *spathic ores* by the smelter; while the term *clay band*, or *clay ironstone*, is applied to the amorphous argillaceous ore found in the coal measures, and *black band* to that containing bituminous or carbonaceous matter. On the Continent, nodular clay ironstone is usually called spherosiderite; but this term more properly belongs to the spheroidal crystalline masses of radiating structure, occasionally found in basalt and other igneous rocks.

The septaria, or cement-stone nodules, found in the London clay, may be regarded as clay ironstones in which the protoxide of iron is in great part replaced by lime: such ores as are too poor to smelt are known as *lean* ironstones.

Association and Distribution of Iron Ores. The definitions of iron ores given in the preceding paragraphs are mineralogical; that is, they present the physical and chemical characteristics of iron-producing minerals when at a maximum of purity. Practically, however, no such pure minerals are to be found on the large scale, and it therefore becomes necessary to consider the manner in which iron ores and other minerals are associated together. The presence of foreign minerals is often as largely concerned in determining whether an ore can be worked to profit or otherwise, as its richness in iron. Thus, a magnetite or hematite deposit, containing 10 per cent. of phosphate of lime or iron pyrites, would be almost useless; while the same amount of manganese in a spathic, or of combustible matter in an argillaceous carbonate, would considerably enhance their respective values. We shall next proceed, therefore, to illustrate these associations by describing some of the more typical iron-mining localities, accompanying the descriptions with analyses of the minerals actually raised.

The geological distribution of iron ores is very unequal; for, although they are found in formations of all ages, the maximum development appears to be in the older rocks. The largest and richest deposits are contained in pre-Silurian strata, such as the Laurentian and Huronian series of North America, and the old gneiss and schists of Scandinavia. Spathic ores are characteristically abundant in the Devonian rocks of Germany and the south of England, being associated in the former locality with red and brown hematites of a high class. The carboniferous period is especially marked by the presence of interstratified argillaceous carbonates both in Europe and America. The most important deposits of red hematite in this country are of Permian age, and are contained in hollows of the carboniferous limestone of Cumberland and Lancashire. In the secondary rocks the chief iron-bearing members are the middle lias, or marlstone, great oolite, wealden, and lower green sand, yielding brown hematites and carbonates which, though of low quality, are of considerable importance, owing to the ease with which they may be mined. In France and Southern Germany large quantities of bean ore, an argillaceous brown hematite, are raised from pipes and other irregular deposits in the oolitic rocks. The tertiary rocks of this country contain very little iron ore, the principal deposit being at Hengistbury Head, in Dorsetshire; but on the Continent the magnificent masses of Elba and Traversella may, perhaps, be of tertiary age.

Of post-tertiary and recent age are the numerous masses of bog iron ore studded over the swamps of Northern Germany, and the lake ores which are constantly forming by infusorial agency at the bottom of the lakes of Norway, Sweden, and Finland.

Magnetic Ores. When massive, these ores usually indicate an excess of peroxide over that required by the formula. They are chiefly confined to the older crystalline rocks of Scandinavia and North America, and appear under two principal conditions: either interstratified in irregular beds or tabular masses in hornblendic and chloritic schists and crystalline limestones, or irregular ramifying veins and masses in dioritic or doleritic rocks. The associated minerals are usually chlorite, hornblende, epidote, garnet, idocrase, phosphate of lime, quartz, felspars, iron and copper pyrites, lievrite, hematite, and brown iron ores. The latter are found chiefly near the surface, and occasionally beautifully crystallised in transverse veins. In the Swedish and Norwegian mines the ore is very commonly intersected by small strings of chlorite called *skölar*. Iron pyrites may be either disseminated in considerable quantity through the ore, which in such cases it generally renders useless, or interspersed in small patches in the neighbourhood of veins of intrusive rock, such as granite. Sometimes the centre of a mass may be pure magnetite, passing at either side into copper and iron pyrites. The texture of massive magnetite appears to vary with the containing rock; the most compact, having sometimes a nearly conchoidal fracture, are found in talcose schist, while the more granular and crystalline conditions prevail in hornblendic gneiss and crystalline limestones.

In the oldest or Laurentian rocks of Canada magnetite is found abundantly in the gneiss and metamorphic limestones of the basin of the Ottawa. The usual form of deposit is in irregular beds, which, although not of any great lateral extent, are often of considerable thickness, in one instance as much as 200 feet. These ores are usually of a very high quality, the associated minerals being chiefly quartz, hornblende, chlorite, serpentine, dolomite, and graphite, but have hitherto only been raised in inconsiderable quantities.

The largest deposit of iron ore in Europe is probably that of Gellivara, in Swedish Lapland, which is situated about ninety miles from the head of the Gulf of Bothnia, in lat. 67° N. According to the descriptions of Erdmann and others, it forms a bold hill rising out of swampy ground, made up of a great number of parallel interlaminations of magnetic and specular iron ores, with hornblendic and quartzose rocks. Several of these beds are between 100 and 200 feet in thickness, and may be traced for distances of 600 and 700 yards in a N.E. and S.W. direction. Phosphate of lime is present in the largest, or 200-feet bed, through about 80 feet of its thickness, the remaining 120 feet being of good quality. Iron pyrites appears to be almost entirely absent. The following analyses of Gellivara ores are by Rinman:—

	I.	II.	III.	IV.
Silica	2·10	3·20	3·10	5·95
Alumina	0·70	0·85	0·85	1·05
Lime	2·10	0·45	2·35	2·40
Magnesia	0·70	1·30	0·60	2·50
Glucina	—	—	0·10	—
Magnetic oxide of iron .	92·10	93·45	90·65	87·80
Phosphoric acid . . .	1·70	0·45	1·17	0·09
	99·40	99·70	98·82	99·79
Metallic iron . . .	67·3	67·7	65·6	63·5

Although these ores have been known for a very long period, but little use has been made of them, owing to the inaccessible character of the country, the only feasible method of transport being by sleighs during the winter months.

In the southern part of Sweden the most celebrated mines are those of Dannemora, situated on the lake of the same name, about thirty-two miles from Upsala. The ore, which is specially employed for producing the highest class of steel iron, is a very fine-grained magnetite, occurring in an irregular interrupted belt about one mile and a half long, in crystalline limestone and petrosilex. The workings on the central part of the mass have been extended to a depth of more than 100 fathoms below the surface. The annual production is, however, small, not exceeding 25,000 tons:—

	I.	II.	III.
Peroxide of iron . . .	58·93	62·06	56·80
Protoxide of iron . . .	27·55	28·42	27·50
Protoxide of manganese . .	0·10	—	0·24
Lime	0·38	traces	1·80
Magnesia	0·61	1·44	0·80
Alumina	0·29	—	—
Sulphur	0·04	0·07	—
Carbonic acid	0·12	—	—
Water	0·11	—	—
Silica	12·54	7·60	13·20
Phosphoric acid . . .	trace	—	—
	100·67	99·59	100·34
Metallic iron	62·6	65·6	61·16

Analysis No. I. of Dannemora ore, by Ward, is of a compact black mineral, containing a very small trace of iron pyrites. Nos. II. and III., by Noad, are of magnetic ores from Roslagen, on the east coast of Sweden, north of Stockholm. No. II., from Höcksta mine, is coarsely crystalline and very slightly coherent, breaking up into sand when subjected to pressure. No. III., from Sladderö Island, is remarkable for its regular structure being divided by joints into rhomboidal prisms. These divisions have been mistaken at times for cleavages of the regular octahedron, but that they are not is evident from their passing through the adjacent gneissic rock, imparting to it a similar structure to that noticed in the ore. Iron pyrites, in small quantities at least, is not uncommon in the magnetic iron ores of southern Sweden, especially in the neighbourhood of granitic veins: an instance of this is afforded by the Jerna mines, situated in an outbreak of coarse granite, and yielding an ore which, although spotted through with iron pyrites, is valuable as an addition to the purer ores of the more northerly districts in the manufacture of strong foundry iron.

Among the most remarkable deposits of magnetic iron in the more southern parts of Europe is that of Traversella, in Piedmont, situated about twelve and a half miles from Ivrea, in the valley of Bersella. It occurs in talcose schists and dolomites in the form of a largely crystalline mass, consisting chiefly of magnetic iron ore, but associated with an extraordinary profusion of other minerals, such as copper and iron pyrites, garnet, chlorite, dolomite, and augite, most of which are beautifully crystallised. The workings have been carried on from time immemorial. About forty miles of galleries have been driven, and the mass, whose thickness varies from 65 to 100 feet, has been removed, at one point, to a depth of more than 200 yards for a distance of about a quarter of a mile. The central portion is formed by an ellipsoid of extremely pure magnetite, accompanied by dolomite, and yielding from 48 to 50 per cent. of iron. The sides are more or less charged with copper pyrites in sufficient quantity to be profitably separated by means of electro-magnetic machines.

At Berggieshübel, in Saxony, magnetite occurs under somewhat similar associations to those observed at Traversella. The deposits are parallel beds from a few inches to twenty feet in thickness, carrying red and brown hematite with sulphate of baryta at the surface, passing downward into magnetite, with garnet, hornblende, and epidote; and at still greater depths, copper ores appear in considerable quantity.

In the neighbourhood of Arendal, in Norway, a series of deposits of magnetite have been worked for several centuries. They extend in a nearly straight line for about thirteen miles parallel to the coast, and are contained in hornblendic and micaceous schists. The ore is mostly pure magnetic oxide without admixture of hematite, and appears in elongated lenticular masses from 6 to 20 feet, but occasionally as much as 70 feet in thickness, whose course is, as a rule, parallel to the foliation of the containing rocks.

The Taberg, near Jonkoping, on Lake Wettern, is an example of the second class of magnetite deposits, where the ore is interspersed in comparatively small strings and masses through a porphyritic rock composed of hornblende and felspar (greenstone or diorite) It forms an isolated hill 366 feet in height, and is extensively wrought, although the produce is low, containing on an average only 25 per cent., as the metal produced is specially adapted for wire-drawing, and fuel is comparatively cheap in the neighbourhood.

At Nischne-Tagilsk and Kuschwinsk, in the Urals, magnetite occurs under somewhat similar conditions to those observed at Taberg, but in a doleritic (labradorite and augite) porphyry. At the former locality, a ridge of rock, 600 yards long, 500 yards broad, and about 250 feet high, is in great part made up of pure magnetic ore; while at the latter it appears to be interspersed through the mass of the augitic porphyry, and towards the summit segregates into a rich workable mass.

In England magnetic iron ore is comparatively rare Near Brent, in South Devon, it is found covering diorite in a crust of about one foot in thickness, the association being similar to that observed in the Urals. At Treskerby, near Penryn, it occurs in a lode about three feet in width, with a slight intermixture of tin ore.

The Cerro Mercado, near Durango, in Mexico, a hill about 300 feet high, is in great part composed of massive magnetite, which in the transverse fissures separates out into octahedral crystals of an inch in diameter. The associated minerals are specular and brown hematite, quartz, and calcspar. The deposit is contained in a felspathic porphyry, fragments of which are found in the ore. Other large deposits of a similar character, on the Pacific side of the country, are supposed by Dana to be contemporaneous in origin with those of Canada and the Northern States of America.

Red Iron Ores. These are often associated with the hydrated varieties of the peroxide, especially in the more earthy deposits contained in secondary and newer rocks; but in the harder crystalline masses, characterising the older formations, such admixtures are less frequent, except near the surface, or in cross fractures, which often contain gothite and other crystalline forms of brown hematite. The most important deposits of these minerals in Europe and America are contained in Huronian, or Cambrian, Silurian, Devonian, and carboniferous rocks. In Sweden, the specular or micaceous variety of hematite occurs, among other places, at Dalkarlsberg, near Nora, and in the island of Utö, in both places associated with magnetite. The Nora ore is made up of parallel stripes of a very brilliant micaceous hematite and quartz, and resembles in composition the Brazilian rock known as itabirite.

On the south shore of Lake Superior, near Marquette, a schistose variety of hematite, known as *specular schist* or *slate iron*, is very largely developed in the Huronian rocks. The iron region extends westward from the lake shore for a distance of about twenty miles, with a breadth averaging six miles. The strata, which are intensely contorted, are chiefly chloritic and talcose schists, passing upward into a rock composed of parallel laminæ of red jasper and hematite, whose total thickness is stated to be upwards of a thousand feet. Out of this amount much is too siliceous, from the great prevalence of jasper, to be worth working; but individual beds of solid hematite, free from earthy matter, of 150 feet thickness, are quarried at the Jackson and Superior mines. A noticeable peculiarity in these ores, in addition to their intensely contorted structure, is the prevalence of minute crystals of the octahedral variety of peroxide of iron, or martite. There are numerous cross veins of secondary origin containing crystallised brown iron ores, and occasionally disulphide of copper in small quantity. Specular schists of a similar character, very finely laminated or contorted, have also been observed on the Canadian shore of Lake Superior, as well as in the altered beds of the Quebec group, belonging to the Lower Silurian series, but on a much smaller scale.

Two celebrated masses of hematite, known as the Iron Mountain and Pilot Knob, are worked near St. Louis, in Missouri. The former consists mainly of massive or specular ore, while the latter is of a similar schistose character to that of the Lake Superior mines.

In Saxony red iron ores are found in the vicinity of Eibenstock and Schwarzenberg, in lodes at the contact of mica schist, altered Silurian rocks, and granite.

These lodes, some of which are as much as 15 fathoms thick, extend longitudinally for nearly twelve miles.

The Devonian rocks, both of England and Germany, contain considerable quantities of red hematite, chiefly in association with brown and spathic iron ores. At Brixham, in Torbay, a brilliant micaceous variety is found in limestone, and is employed, when ground in oil, as a paint for covering iron work. A similar substance, of a brilliant red colour, is obtained at Audeghem, in Belgium, which is sold for the same purpose, under the name of "minium de fer," and is recommended for use in coating marine boilers in preference to red-lead.

The largest deposit of iron ore in Cornwall is that worked at Restormel, near Lostwithiel, where a lode, having an average thickness of from 12 to 16 feet, occasionally increasing to 20 feet, has been followed for more than a mile. The principal mineral is crystallised brown hematite or göthite, which occurs in fibrous and mammillated aggregates, and also in long prismatic crystals of great beauty. Less frequent are red hematite, and hard and soft manganese ores. Crystals of carbonate of iron altered to brown hematite are occasionally seen in the upper levels. Owing to the prevalence of manganese, these ores are well adapted for making steel irons.

By far the most important hematite mines in this country, are those of Ulverstone, in Lancashire, and Whitehaven, in Cumberland, which occur in very irregular deposits in the carboniferous limestone. Near Cleator, the ore forms a bed of from 15 to 60 feet in thickness, apparently interstratified between a shale floor and a limestone roof. It is for the most part of a dull compact character, but forming kidney-shaped crystalline aggregates in the cavities where crystals of quartz and arragonite are also common, together with specular iron. In the Ulverstone district the ore is usually found filling irregular cavities in the limestone. In addition to the compact, a greasy micaceous variety is largely produced, and is used for lining the hearths of puddling furnaces. In both districts brown hematite appears to be entirely absent; iron pyrites and phosphate of lime can be detected in minute traces chemically, but are not apparent to the naked eye. The following analyses are sufficient to show the extreme purity of these ores:—

	I.	II.	III.
Peroxide of iron . .	90·36	95·16	94·23
Protoxide of manganese .	0·10	0·24	0·23
Alumina	0·37	—	0·51
Lime	0·71	0·07	0·05
Magnesia	0·06	—	—
Phosphoric acid . .	—	—	0·09 { Sulphuric acid.
Bisulphide of iron . .	0·06	—	0·03
Insoluble residue . .	8·54	5·68	5·18
	100·20	101·15	100·32
Metallic iron	63·25	66·6	65·96

Nos. I. and II. Hematites from Cleator Moor, Whitehaven, by Dick.
No. III. " Lindale, Ulverstone, by Spiller.

Since the intoduction of the Bessemer process, a large additional demand has sprung up for hematite pig iron, and these ores are smelted to a great extent in the immediate vicinity of the mines. In addition to the local consumption, a considerable quantity is exported, to be used in other iron-making districts, either as a mixing ore or in the puddling furnace.

The following series of analyses gives the composition of the red hematite ores, employed for making Bessemer pig iron at Barrow-in-Furness iron works, Lancashire.

	I.	II.	III.	IV.
Peroxide of Iron	91·88	77·21	83·33	83·94
Alumina	0·07	1·71	0·75	0·70
Protoxide of manganese .	0·04	0·11	0·08	0·28
Lime	0·34	6·08	4·10	0·85
Magnesia	trace	0·41	0·15	0·09
Water	0·47	2·82	1·97	2·28
Phosphoric acid	0·03	—	—	0·03
Sulphuric acid	—	—	trace	—
Carbonic acid	—	4·19	2·53	—
Silica	4·55	7·36	6·59	12·46
	100·38	99·92	99 50	100·63
Metallic iron	66·42	54·07	58·33	58·76

I. Park ore (best rough); II. Lindal Cote (puddling); III. Whitrigg's (puddling); IV. Mouzell mine (best). Analyses by Richards.

A remarkable deposit of red hematite has recently been opened, and is now in process of development, at Cwm mountain, in Flintshire, near Prestatyn, and a short distance from the famous lead mine of Talargoch. The ore occurs almost entirely as a breccia of angular fragments cemented by crystalline carbonate of lime, filling large irregular lodes in the carboniferous limestone. Brown hematite is also found, but in smaller quantity; some of it being in octahedral crystals probably pseudomorphous after magnetite which is a somewhat rare occurrence. Unlike the northern hematite deposits, quartz is extremely rare. The calcspar is highly crystallised, but while preserving its characteristic form is coloured of a deep brick-red tint by finely diffused peroxide of iron.

At Whitchurch, near Cardiff, in Glamorganshire, an oolitic variety of red hematite occurs at the base of the carboniferous limestone. It is also found in the same geological position in the valley of the Meuse, near Huy and Namur, in Belgium; and on the Cumberland river, in Kentucky—a curious fact, showing that similar conditions prevailed at the commencement of the carboniferous period in areas widely removed from each other.

A remarkable bed of calcareous brown hematite occurs in the Cheadle coal-field in North Staffordshire, at the base of the coal measures. Although its maximum thickness is only 22 inches, it has been extensively used for export to South Staffordshire, where it is used as a mixture with the more siliceous ores of other districts.

In the Forest of Dean, and in the neighbourhood of Bristol, as well as at Llantrissant, in Glamorganshire, irregular masses of brown hematite are met with in the carboniferous limestone and the lower coal-measure sandstones. At the last of the above-mentioned localities the ore is interstratified between the upper part of the carboniferous limestone, in which it forms an irregular bed, filling holes and depressions, and a black shale roof, supposed to be a portion of the coal measures, which is filled with nodules of argillaceous carbonate of iron. The Forest of Dean ore is a stalactitic brown hematite, locally known as brush ore, the more earthy varieties being distinguished by the term smith ore. The following analyses give the composition of the ores of this district:—

BROWN HEMATITES FROM CARBONIFEROUS ROCKS.

	I.	II.	III.	IV.
Peroxide of iron	90·05	89·70	59·05	52·83
Protoxide of manganese	0·08	0·04	0·09	0·81
Lime	0·06	0·49	0·25	14·61
Alumina	—	0·63	—	—
Magnesia	0·20	0·40	0·28	5·70
Carbonic acid	—	—	—	18·14
Phosphoric acid	0·09	0·13	0·06	0·32
Sulphuric acid or pyrites	—	—	0·09	0·28
Silica	—	—	34·40	—
Water	9·22	7·05	6·38	4·75
Organic matter	—	—	—	1·30
Insoluble residue	1·07	2·57	—	0·04
	100·77	101·07	100·60	98·78
Metallic iron	63·04	62·86	41·34	36·98

No I. Black brush ore, from Forest of Dean, by Dick.
„ II. Smith ore „ „ „
„ III. Llantrissant ore, Glamorganshire, by Riley.
„ IV. Calcareous hematite, "hydrate of iron," from Froghall, by Dick.

The brown hematite of Ashton Court, near Bristol, is remarkable for occasionally containing fragments of sulphate of baryta, interspersed like felspar crystals in a porphyry.

On the west side of the island of Elba, specular iron ore has been worked for a period of 2,500 years. The deposits are contained in metamorphic rocks, whose age is not precisely determined, being variously stated as belonging to the carboniferous, cretaceous, or tertiary periods. At Rio Marina, hematite partly specular and partly massive, rests upon talcose schist, and is covered by crystalline limestone, but the work has recently been confined to turning over rubbish heaps left by the old miners, which are piled up to a height of 500 feet above the ground level. At Rio Allane and Terra Nera the mineral appears in lodes traversing talcose schist, which send off numerous strings, enclosing fragments of the rock, and afterwards overlie it, forming beds of from 30 to 100 feet in thickness. At Cape Calamita a similar ramifying lode is seen in a limestone cliff which rises precipitously from the sea. It contains magnetite below, passing upwards into a mixture of specular iron and lievrite.

A schistose variety of hematite, somewhat similar in character to that of Lake Superior, is found in the Devonian limestones of Nassau. At the mine of Gottesgabe several beds of from 1½ to 4 feet in thickness, making up a total of from 36 to 40 feet, are intercalated in schistose calcareous greenstones and beds of *eisenkiesel*—a concretionary rock, made up of red and brown iron ore and fragments of bright red jasper. In the same formation irregular pockets of brown and red ores, associated with pyrolusite and other manganese ores, are found in the hollows of the limestone beneath the gravels and brick earth forming the surface soil. Occasionally these ores are entirely replaced by phosphate of lime in similar irregular masses.

Titaniferous Iron Sands.—In nearly all crystalline rocks, hematite or magnetite, usually titaniferous, is very commonly found, disseminated through the mass in the form of fine grains or crystals. When such rocks are subjected to disintegration, the ferruginous minerals are set free and give rise to the substance known as *black-sand*, which, from its high specific gravity, is easily separated by the action of water from the lighter minerals—quartz, felspar, &c., accompanying it. One of the most familiar instances is afforded by the process of alluvial gold-washing, where the first operation consists in concentrating the gold in a small volume of black sand, which is afterwards removed either by a magnet, or more generally by careful washing in a pan or batea. Along the sea-shore, especially in countries where granites or other crystalline rocks occur, streaks of black sand, washed out by the action of the waves from the associated siliceous minerals, are very commonly found upon gently sloping portions of the beach; and in some instances the quantity is so large that it may be utilized as an iron ore. Among these localities may be mentioned the shore of the Bay of Naples, Taranaki in New Zealand, and more particularly the whole of the north-east coast of British America; the more important deposits being situated along the north shore of the St. Lawrence, from the Moisie River eastward. These sands are derived from the waste of the Norite, or Labradorite rock, which forms a great part of the Upper Laurentian, or Labrador series of the Canadian geologists, consisting of a mixture of Labrador felspar, hypersthene, magnetite, and titaniferous iron ore. Sometimes the latter mineral is found in good-sized blocks, as, for instance, at Mingan, being obviously derived from a mass of ore. At Moisie, where these sands form the beach, they are exposed to the action of the waves which effect a process of concentration so that after a prevalence of certain winds great belts of nearly pure black sand are exposed along the shore. When visited in 1868 by Dr. Sterry Hunt, trenches were being sunk to a depth of 5 feet on the shelving beach about half way between high and low water marks. The sections presented alternations of nearly pure siliceous sand and of black iron-sand, the latter in layers of from half an inch to 6 inches in thickness, often with a small admixture of grains of red garnet. The thicker layers of moist black sand were easily removed by shovels from the more siliceous part, and amounted by measure to about one and a half or two feet of the total thickness of five feet excavated. The ore was subjected to a further separation by dressing on a shaking-table, about 20 feet long and 4 feet wide, with a somewhat concave surface, upon which, by the aid of a gentle current of water, a further portion of the lighter grains, consisting chiefly of quartz, was washed away, so that the ore as prepared for smelting contained but 5½ per cent of insoluble siliceous matter.

When freed entirely from the associated earthy minerals, the black iron sands may be divided into a magnetic and a non-magnetic portion; the former being nearly pure magnetite, while the latter is chiefly titaniferous iron ore. The following analyses, by Sterry Hunt, give the composition of the dressed sand smelted at Moisie iron-works.

	I.	II.	III.
Protoxide of iron . . .	85·79	56·38	70·10
Titanic acid	4·15	28·95	16·00
Protoxide of manganese . .	0·40	1·10	—
Lime	0·90	0·95	—
Insoluble residue . . .	1·95	8·75	5·92
Total	93·19	96·13	92·02
If estimated as magnetic oxide	92·68	—	—
Metallic iron	66·73	43·85	55·23

I. Magnetic portion of dressed ore; II. Non-magnetic portion; III. Unwashed black sand: as a whole, it corresponds in composition to about equal parts of I. and II. In these analyses the iron is expressed as protoxide, though a portion of it occurs in a higher state of oxidation, as it is difficult to determine exactly the proportion of the two oxides in the presence of titanic acid. At Mingan, Natasquan, and several other points along the Labrador coast, iron sands occur under generally similar conditions to those described by Dr. Sterry Hunt. The siliceous portion which remains after the removal of the heavier metallic grains, is found, when examined under the microscope, to contain in addition to quartz and garnet, cleaved fragments of felspars, which often include well-formed octahedra of magnetite.

The production of cast iron from magnetic sand is attended with considerable difficulty, as the fine state of division of the ore renders it unfit for treatment in the blast furnace. Various processes have been suggested for overcoming this defect, the principle most generally in favour being that of agglomerating the sand with clay and other earthy matter, so as to form it into lumps, which can then be used in the blast furnace in the same way as ordinary ores. None of these processes have, however, been sufficiently successful to require further notice, and it is only within the last few years that the black sand of the Labrador has been treated to advantage, by converting it into wrought iron directly in the open fire or bloomary furnace, a notice of which will be found at the end of Chapter XII.

Brown Iron Ores of the Secondary Formations. In the lias, oolitic, and lower greensand formations, brown hematites, mostly of an impure and sandy character, are found almost continuously from the northern parts of Wiltshire to the wolds of Yorkshire, passing through Oxfordshire, Northamptonshire, and Lincolnshire, usually appearing as a dark, ochreous, brown, oolitic rock, occasionally having a greenish cast on a freshly-fractured surface. The most important bed is that occurring in the lower part of great oolite, from the neighbourhood of Banbury through Northamptonshire.

Although of low quality, the ease with which they may be quarried has caused these ores to be largely wrought for export to Staffordshire and South Wales, besides being smelted in furnaces erected on the spot. In some places, the Northamptonshire ore appears to be the result of an alteration of an argillaceous carbonate of a similar character to that worked in the North Riding of Yorkshire, under the name of the Cleveland Ironstone. At Westbury, in Wiltshire, the same ore is found in the coral rag; and at Seend, near Devizes; and Linslade, in Buckinghamshire, in the lower greensand. In the last-mentioned locality there is no continuous bed, but large nodular masses of brown ochreous limonite are found scattered through about 50 or 60 feet of brown sand. The nodules are often hollow, and filled with loose white sand.

Analyses of Brown Iron Ores from the Secondary Formations.

	I.	II.	III.		IV.
Peroxide of iron .	44·67	64·61	67·8		52·86
Protoxide of iron .	0·86	—	—		—
Alumina . .	9·10	3·85	8·5		7·39
Protoxide of manganese . .	0·44	—	0·7		0·51
Lime . . .	9·29	0·64	2·8		7·46
Magnesia . .	0·66	0·20	0·8		0·68
Phosphoric acid .	0·55	0·64	2·3		1·26
Carbonic acid .	6·11	—	0·1	{ Vanadic acid	4·92
Silica . . .	12·34	18·02	7·9		13·16
Sulphur. . .	trace	—	0·1	{ Arsenic acid	0·03
Water . . .	16·31	11·85	10·3		11·37
	100·33	99·81	101·3		99·64
Metallic iron . .	31·94	45·22	47·5		37·00

No. I. From the middle lias (marlstone), Fawler, near Blenheim, by Dick.
„ II. Lower greensand ore, Seend, Wiltshire, by Riley.
„ III. Oolitic ore (bohnerz), White Jura, Kandern, Bavaria, by A. Müller.
„ IV. From the Northampton sands, in the great oolite, Wellingborough, by Spiller.

In France red and brown hematite occur in oolitic and liassic rocks, under somewhat similar conditions to those observed in this country, the most important deposit being that of La Voulte, in the Ardèche, where three beds of a compact earthy red hematite, varying 3½ to 16 feet in thickness, are interstratified in marls which are variously stated as belonging to the lias or the Oxford clay. Oolitic varieties of the same minerals are found in all three divisions of the series; but, as a rule, they are more argillaceous than the English ores of the same age.

In Bavaria and Wirtemberg, the lower members of the oolitic group or brown Jura formation contain similar ores, on the north-west side of the Swabian Alps, the maximum thickness observed being 18½ feet in the neighbourhood of Aalen and Wasseralfingen. Another large development in the same formation in the Grand Duchy of Luxembourg extends into the French portion of the Moselle valley, and forms one of the most important and productive iron districts on the continent of Europe.

Besides the stratified ores above noticed, the South German oolites often contain irregular masses of loose concretionary brown hematite, known as bean ore (bohnerz), filling cracks or funnels in the eroded surfaces of limestones. These concretions vary from the size of a small pea up to that of a walnut, the larger being less perfectly spherical than the smaller ones.

The cementing material is a ferruginous sand or clay, which is sometimes sufficiently compact to form a kind of breccia; but, as a rule, it is unconsolidated, and may be removed from the ore by washing, which, when prepared for smelting, contains about 36 per cent. of iron.

Sandy brown iron ores, forming superficial deposits, are worked at many places in the Wealden rocks of the Boulogne district, for the supply of a large range of furnaces at Marquise, between Boulogne and Calais.

Bog Iron Ore—Limonite. Although not found in this country in sufficient quantity to be worth working, these ores are abundantly developed in Europe, especially on the great plain of North Germany, which extends from the borders of Holland to the head of the Baltic. They are of very variable composition and quality, and, in addition to the hydrated peroxide, often contain protoxide of iron in combination with humic and other organic acids, and silica. According to Ehrenberg the formation of bog ores is in part due to infusoria (diatomaceæ), which have the power of separating iron from water, and depositing it as hydrated peroxide in their siliceous coverings.

In Sweden, Norway, and Finland large quantities of a variety of limonite, known as lake ore (*sjomalmer*), are obtained by dredging from the bottom of the numerous lakes studding the surfaces of these countries. It occurs in granular concretionary forms, varying in size from that of grains of coarse gunpowder up to cakes of 6 inches in diameter. The work of collecting these ores is confined to the winter months, the raising being effected by a perforated iron shovel fixed to the end of a long pole, which is lowered through a hole about three feet in diameter made for the purpose in the ice. The ore, which occurs in layers varying from 8 to

30 inches in thickness, from 10 to 200 yards in length, and from 5 to 15 yards in breadth, is continually forming; and localities that have been exhausted have been known to present fresh workable deposits of several inches in thickness after a lapse of twenty-six years. The formation of these ores is said to be mainly due to infusorial agency, the iron being derived either from the oxidation of iron pyrites or silicates of protoxide of iron, such as hornblende, pyroxene, &c., in the adjacent rocks. Probably the bean ores of the German oolitic rocks, which are very similar in structure and composition, may have been formed in like manner. Bog and lake ores vary very much in composition and quality: usually, however, they contain a marked quantity of phosphorus, and are best adapted for foundry purposes. A variety of grey pig iron, made from bog ore at Batiscan, Three Rivers, Canada, is largely employed for making railway wheels, on account of the facility with which it chills when cast in metal moulds.

ANALYSES OF BOG AND LAKE ORES.

	I.	II.	III.	IV.
Peroxide of iron . . .	62·59	66·28	67·59	77·60
Protoxide of iron . .	—	2·70	—	—
Oxide of manganese . .	8·52	—	1·45	0·30
Silica	—	—	7·81	5·40
Sand	11·37	13·50	—	—
Alumina	—	—	4·18	—
Lime	—	—	0·47	—
Magnesia	—	—	0·23	—
Phosphoric acid . . .	1·50	1·27	0·18	1·81
Sulphuric acid . . .	trace	—	—	—
Humus (apocrenic acid) .	—	9·00	—	—
Water and organic matter .	16·02	7·50	17·81	17·25
	100·00	100·25	99·72	102·36
Metallic iron . . .	43·82	48·50	47·32	54·32

Nos. I., II. Bog ores from the neighbourhood of Lingen, **Hanover**, by Senft.

„ III. Lake ore from Flaten, Wermland, Sweden, by Svanberg.

„ IV. Bog ore from Three Rivers, Canada. The excess in the analyses is due to part of the iron existing as protoxide. By Sterry Hunt.

Spathic Carbonate of Iron. This ore, though of less frequent occurrence than the various forms of peroxide, appears in a few localities in Central Europe in masses which, for extent and value, may be fairly paralleled with the "iron mountains" of Scandinavia and North America. The principal English deposits are those of Weardale, in Durham, where it occurs in lodes in the carboniferous limestone associated with lead and zinc ores, Perran in Cornwall, Exmoor in North Devon, and Brendon Hill in Somerset. Between the two last-mentioned localities the ore forms a chain of lodes in the middle Devonian rocks, said to be about five miles long, with a maximum thickness of 27 feet. Latterly they have been worked to a considerable extent for export to South Wales, where they are successfully employed in the production of spiegeleisen. In all cases the higher part of the lode is changed into brown hematite to a considerable depth by the action of atmospheric air and water.

In the Devonian rocks of the Rhine, large quantities of spathic ores are found in the district of Siegen, the most important deposit being that called the Stahlberg, or steel mountain, near Müsen, where a nearly vertical wedge-shaped lode in clay slate has been worked since A.D. 1313. The greatest thickness of this mass is about 65 feet, the horizontal extension about 160 yards, and the height or depth, which has been proved by twelve working levels driven into the hill, 260 yards. The annual production is about 30,000 tons. In the adjoining mine, called Schwabengrube, the same lode splits up into numerous smaller ores, and carries cobalt, copper, and lead ores.

In the Eastern Alps spathic iron ores are largely developed in metamorphic rocks, chiefly micaceous and talcose schists, and crystalline limestones of Devonian or perhaps Silurian age. Near Eisenerz, in Styria, the celebrated "Erzberg," or ore mountain, which rises to a height of about 2,500 feet, apparently consists of a solid mass of carbonate of iron, but is in reality only covered by a capping or arch of the mineral, which varies in total thickness from 200 to 600 feet, including a few interstratified schistose partings. The deposit lays upon, and apparently passes on either side into, limestone, and is covered by a breccia of limestone fragments and clay slate. The best ore, which is hard crystalline, and of a brownish-yellow colour, known locally as "pflinz," occurs in the lower beds. The associated minerals are iron and copper pyrites, quartz, carbonate of lime, and more rarely cinnabar. The annual production is about 110,000 tons, more than 50,000,000 tons being laid open in the workings.

Of a similar character, but smaller in extent, are the deposits of spathic ores in Carinthia. These are situated at Hüttenberg and Lölling, north-east of Klagenfurth, and include a series of lenticular beds in crystalline limestone, the largest being nearly 200 feet thick, containing, in addition, small quantities of heavy-spar, mica, chalcedony, and occasionally arsenical pyrites and scorodite.

In the Permian rocks of Thuringia a large irregular mass of spathic ores has been worked in the Mommel and Stahlberg mines, near Schmalkalden, for more than 700 years. It is of very variable form, being much disturbed by intruded granitic and porphyritic veins, but is in places nearly vertical, with a breadth of

500 feet, and has been followed to a depth of 300 feet. The known length is about a mile.

ANALYSES OF SPATHIC IRON ORES.

	I.	II.	III.	IV.	V.
Protoxide of iron . .	49·47	43·84	53·42	55·64	47·96
Protoxide of manganese .	2·42	12·64	3·08	2·80	9·50
Peroxide of iron . .	—	0·81	—	—	—
Lime	3·47	0·28	—	0·92	—
Magnesia. . . .	3·15	3·63	5·00	1·77	3·12
Carbonic acid . . .	37·71	38·86	38·10	38·35	39·19
Phosphoric acid . .	trace	—	—	—	—
Silica	4·93	—	0·06	—	—
Bisulphide of iron . .	0·08	—	—	—	—
	101·23	100·06	99·66	99·48	99·77
Metallic iron . . .	38·56	34·65	41·51	43·26	37·31
„ manganese .	1·86	9·73	2·37	2·16	7·31

No. I. from Weardale, Durham, contains traces of lead and copper. Dick.
„ II. „ Brendon Hill, Somersetshire; streaked with red hematite. Spiller.
„ III., IV. „ Eisenerz, Styria. Haidinger.
„ V. „ Stahlberg, Müsen. Fresenius.

Argillaceous Carbonate of Iron. This is by far the most important of British iron ores, furnishing nearly two-thirds of the total annual iron produce of the United Kingdom. It is found either in irregular nodules, interspersed through the clays or shales of the coal measures, and in a much less degree in some of the argillaceous members of the secondary and tertiary rocks, or in beds of several feet in thickness, and continuous over considerable areas; in the secondary formations, more especially in the lias. The former, or nodular variety, consists essentially of masses of carbonate of iron of a compact or earthy fracture, which, in addition to variable proportions of carbonates of the isomorphous bases, lime, magnesia, and manganese, always contain a notable quantity of clay. The nodules occasionally coalesce into beds, which are, however, usually restricted both in thickness and extent. The irregular forms are often concretionary, and contain fragments of fossils, such as fish, small crustaceans, freshwater shells, or the remains of plants. It is very common to find the nodules divided by small fissures, analogous to those produced by the contraction of clay in drying, which are filled up with other minerals, forming miniature lodes; the most general associates being iron and copper pyrites, galena, blende, carbonate of lime, quartz, and the rare substances, Millerite, or sulphide of nickel, and Hatchettine, or mineral tallow, the two latter minerals being found together in the clay ironstone of Dowlais, near Merthyr Tydvil, in Glamorganshire. When freshly broken the nodules are usually of a light grey, yellow, or bluish tint, but become brown on exposure by the superficial peroxidation of the iron. Phosphoric acid is almost invariably present, ranging in amount from 0·05 to rather more than 1 per cent.

The coal-fields most abundantly supplied with these ores are those of South Wales, North and South Staffordshire, Shropshire, Yorkshire, and Derbyshire, Scotland, and Denbighshire; while, on the other hand, scarcely any are found in the great Northumberland and Durham basin, or that of Lancashire. They are often worked in conjunction with coal seams in the same pits either simultaneously or at different times.

The yield of ironstone measures per acre varies considerably, on account of the great irregularity in the distribution and thickness of the nodules. Thus, in the Barnsley district, the Tankersley Mine, a bed of shale 6 feet thick, with from 12 to 15 inches of ironstone, yields about 2,000 tons to the acre; the Parkgate

Old Black Mine, 11 inches thick, 1,500 tons; while the Clay Wood Mine, only 5½ inches thick, produces from 1,500 to 1,600 tons. In Derbyshire the Black Shale rake of Chesterfield is the most productive measure, yielding from 4,000 to 7,000 tons per acre: it consists of twenty bands of nodules, varying from ½ to 2½ inches thickness, or 28 inches in all, interspersed through a total thickness of about 36 feet of shale.

ANALYSES OF CLAY IRONSTONES.

	I.	II.	III.	IV.	V.
Protoxide of iron	36·14	47·87	39·55	44·33	44·29
Peroxide of iron	0·61	—	2·71	1·06	—
Protoxide of manganese	1·38	1·12	1·50	1·00	1·13
Alumina	0·52	0·43	1·14	0·92	0·45
Lime	2·70	1·00	3·32	2·86	3·06
Magnesia	2·05	1·27	2·85	1·97	3·73
Carbonic acid	26·57	30·96	28·63	30·92	32·48
Phosphoric acid	0·34	0·07	1·12	0·70	0·42
Bisulphide of iron	0·10	0·25	0·05	0·07	—
Water	1·77	1·18	1·75	1·30	1·45
Organic matter	2·40	0·41	1·14	0·48	0·35
Insoluble residue	25·27	15·95	15·80	14·35	13·01
	99·85	100·51	99·56	99·96	100·37
Metallic iron	29·12	36·56	33·20	35·61	34·72

No. I. Low Moor Black Bed, near Bradford. Insoluble residue, chiefly clay. Spiller.

„ II. Fireclay balls, Dudley, South Staffordshire. Dick.

„ III. Dale Moor Rake, Stanton, Derbyshire, contains traces of zinc and copper. Spiller.

„ IV. White Flats ironstone, Shropshire. Spiller.

„ V. Lumpy Vein Mine, Dowlais, South Wales, contains, in addition, 0·14 of potash. Riley.

Blackband Ironstone. This term is applied to clay ironstones containing carbonaceous matter. These are usually of a dark brown or black colour, and often of a shaly structure, resembling cannel coal. They are very valuable ores, from the ease and cheapness with which they may be calcined by burning in heaps without any additional fuel, the residue yielding from 50 to 70 per cent. of iron. Blackband was discovered in Lanarkshire by Mushet in the year 1801, and has since been worked to a very great extent, but the supply is now falling off. In the Western coal-field of Scotland seven principal blackband measures are known, having the following average thicknesses :—

Palace Craig blackband	. . .	12 inches.
Airdrie ,,	. . .	16 ,,
Bellside ,,	. . .	6 ,,
Kiltongue ,,	. . .	8 ,,
Calderbank or Kennelburn blackband	.	6 ,,
Upper slaty ,,	.	15 ,,
Lower slaty ,,	.	8 ,,

The above thicknesses are subject to considerable variation, and the same bed is rarely continuous over any very large area without change of composition. Thus the Airdrie blackband is found in workable quantity within an area of only ten square miles, but its equivalent in the form of a thin coal covers from fifty to sixty square miles. The slaty band, in like manner, is represented in Linlithgowshire by the celebrated Boghead cannel coal.

The yield of blackband ironstones is at the rate of 2,000 tons calcined ore, equal to 1,000 tons of pig iron, per acre for each foot of thickness. In North Staffordshire blackband occurs in beds from 4 to 9 feet in thickness, and is largely exported in the calcined form for use in the South Staffordshire furnaces. In South Wales it is found in numerous small irregular beds, more especially in the western part of the coal-field. More recently similar ores have been discovered in the Rhenish and Westphalian coal-fields.

In South Wales, a carbonaceous spathic ore occasionally accompanying the coal is known as *coal brass*, a term which is also applied to the nodules of iron pyrites found under similar circumstances. It differs from blackband in containing considerable quantities of carbonates of lime and magnesia.

ANALYSES OF BLACKBAND IRONSTONES.

	I.	II.	III.	IV.
Protoxide of iron . .	46·53	50·73	43·37	37·07
Peroxide of iron . . .	—	0·45	4·10	—
Protoxide of manganese .	2·54	1·86	1·50	0·23
Alumina	0·97	0·26	6·05	—
Lime	2·41	2·52	3·00	6·61
Magnesia	1·39	1·26	0·25	7·40
Carbonic acid . . .	30·77	33·89	30·50	36·14
Phosphoric acid . . .	0·69	0·73	trace	0·23
Bisulphide of iron . .	0·38	0·38	1·56	trace
Water.	1·47	—	0·58	—
Organic matter . . .	10·46	6·41	6·25	9·80
Insoluble residue. . .	2·27	0·72	2·80	2·70
	99·88	99·21	99·96	100·18
Metallic iron . . .	36·39	39·84	36·49	28·83

No. I. Red shag ironstone, Shelton, North Staffordshire. Dick.
„ II. Red Mine, Apedale, North Staffordshire. Dick.
„ III. Blackband, Abercarne, Monmouthshire. Rogers.
„ IV. Coal brass, South Wales. Price and Nicholson.

Cleveland Ironstone. It has already been stated at p. 67, that the middle lias or marlstone rock bed near Chipping Norton and Woodstock, in Oxfordshire, assumes the form of an oolitic brown hematite, being apparently the result of atmospheric action upon an impure variety of protocarbonate of iron. In the North Riding of Yorkshire the same bed contains an ironstone, but on a larger scale than prevails further westward. Where it is best developed, the stone has a total thickness of about 20 feet, made up of various interstratified bands of ore, shale, and iron pyrites, out of which two principal members are distinguished as the *Pecten* and *Avicula* seams, from the respective prevalence in them of fossil shells belonging to these genera. The greatest workable thickness of the bed is from 12 to ~~17~~ feet; the average yield is estimated at about 20,000 tons per acre. The usual colour of the ore is a dull bluish green, from the prevalence of a silicate of protoxide of iron; in structure it is oolitic, with numerous interspersed fossils. At Rosedale Abbey, a dark blue or black variety is found, which, although oolitic, is both magnetic and polar, and appears in many respects to be similar in character to the mineral known as *Chamoisite*, worked at Chamoisin, in the Valais.

ANALYSES OF CLEVELAND IRON ORES.

	I.	II.	III.	IV.
Protoxide of iron	33·17	43·35	33·85	39·92
Peroxide of iron	—	1·20	32·67	3·60
Protoxide of manganese	0·50	—	0·69	0·95
Alumina	3·92	9·88	3·15	7·86
Lime	11·90	0·58	2·86	7·44
Magnesia	4·52	5·35	1·59	3·82
Silica	—	7·65	6·95	7·12
Carbonic acid	28·00	22·96	10·36	22·85
Phosphoric acid	0·48	3·87	1·41	1·86
Bisulphide of iron	—	0·09	0·03	0·11
Water	3·65	5·07	4·60	2·97
Insoluble residue	13·22	—	—	1·64
	99·36	100·00	98·16	100·14
Metallic iron	25·80	34·54	49·17	33·65

No. I. Avicula, or lower bed, Grosmont, Yorkshire. Tookey.
„ II. Main seam, Eston Nab. Crowder.
„ III. Magnetic ore of Rosedale Abbey. Pattinson.
„ IV. Cleveland ore; locality not stated. Sum includes 0·27 potash. The silica exists mostly in the soluble form. The residue contains visible crystals of titanic acid (anatase). Dick.

For the following systematic account of the localities where iron ores are worked in the secondary formations in England, I am indebted to my friend Mr. J. W. Judd, of the Geological Survey, who has paid particular attention to the geology of these deposits.

I. MIDLAND COUNTIES. A. *Marlstone rock bed.* This, the highest portion of the middle lias series, is usually ferruginous, and in certain localities forms a good ironstone. It is a bed which at times attains a thickness of more than twenty feet. The ore resembles, in many respects, that from the Northampton sand, but is calcareous rather than siliceous.

The localities where it has been worked are as follows:—

1. Adderbury in Oxfordshire, between Banbury and Deddington: these works yielded, in 1869, 10,167 tons; and a few months since they were still in active operation, and in process of extension.

2. Steeple Ashton, Oxfordshire. Here the Northampton sand was raised at the surface, and the marlstone rock-bed at a depth of 30 feet, both being sent away as iron ore.

3. Fawler, near Stonesfield, Oxfordshire. The rock-bed was worked for several years, but lately, the workings have been stopped, owing to the great depth of bearing or cover that has to be stripped to get at the ore.

B. *Northampton Sand.* The beds worked in this formation belong to the lowest portion of the Inferior Oolite (zone of *Ammonites murchisoniæ*), and are the equivalent of the Dogger of Yorkshire. The ferruginous beds usually form the base of the formation, and rest directly on the Upper Lias clay. The good ore seldom exceeds from 8 to 10 feet in thickness. It is a siliceous brown hematite, usually of poor quality, but useful on account of the low price at which it can be raised, as a mixture for the more expensive clay-band ironstones of the coal measures.

The Northampton sand is dug for iron ore at Blisworth, Duston, Wellingborough, Irthlingborough, Coggenhoe, Glendon, Finedon, Gayton, Brixworth, Woodford, Islip, Slipton, Desborough, and Stow, in Northamptonshire; Steeple Ashton and Heyford, in Oxfordshire; and Neville Holt, in Leicestershire. The annual yield of the different workings cannot be less than 700,000 tons. The greater part of the ore is sent away to South Wales, Derbyshire, and South Staffordshire, but a large amount is also smelted on the spot at Wellingborough, Irthlingborough, Glendon, and Heyford.

Cinder heaps and other evidence of old iron workings, abound almost everywhere on the Northampton sand. Near Oundle, and at Duston, Roman remains have been found in association with the cinder heaps.

There is historical evidence that in Norman times, iron was made extensively all over Rockingham forest; and Rockingham Castle is said to have been originally erected for the defence of these furnaces, more probably to control the iron workers.

Besides the localities noticed above, the Northampton sand covers large areas in Oxfordshire, Northamptonshire, Leicestershire, Rutlandshire, and Lincolnshire, which would yield immense supplies of ore if opened up by railways.

II. LINCOLNSHIRE. A. *Lower Lias.* These beds form the top of the series known as the Lower Lias limestone and shale, and are characterized by the great abundance of *Gryphæa arcuata.* The ironstone bed, 27 feet thick, is dug at Scunthorpe and Frodingham in North Lincolnshire. In 1869 220,524 tons of ore were raised, while 33,786 tons of pig iron were made in six blast furnaces on the spot. Originally the ironstone smelted at this point was collected in the form of rolled fragments from the alluvium, and it was only on removing the cover that the thick bed now worked was discovered.

B. *Middle Lias.* Two beds of ironstone, the upper one measuring 8 feet and the lower 4 feet in thickness, are met with in North Lincolnshire. They are probably the equivalent of some of the Cleveland ironstones. As far as is known, they are not used at present. Ironstone probably of this age was formerly worked at Kirton in Lindsey, also it has been found at a point N.W. of the city of Lincoln, and attempts made to get a railway for the convenience of working it. The marlstone rock in places forms a good ironstone in South Lincolnshire, and there is evidence of its having been worked in ancient times.

C. *Northampton Sand.* Inferior Oolite. This was extensively worked in olden times in South Lincolnshire, but at present no workings are carried on in this formation anywhere within the boundaries of the county.

D. "IRONSTONE JUNCTION BED" at the base of the "upper estuarine series," the equivalent of the Stonesfield slate of the south of England. This is a band of good ironstone, and although not more than a foot in thickness, was often worked in ancient times.

E. "Ironstone balls of the GREAT OOLITE CLAY."

A few years ago a considerable quantity of ore was raised from this formation, which is the equivalent of the Forest marble of the south of England, at Overton near Peterborough: but the workings have been abandoned on account of the large amount of waste material requiring to be removed. Similar ironstone balls of good quality are frequent in the lower part of the middle and upper part of the Lower Lias, but they have not as yet been turned to account.

F. *Neocomian.* In the beds of the "Tealby series" or Middle Neocomian, is found a brown ironstone made up of oolitic grains exactly similar to that of Steinlahde and Osterholz, near Salzgitter, in Hanover, which is of the same geological age. This useful bed of ore, averaging 6½ feet in thickness, is full of fossils, and highly calcareous, yielding from 28 to 33 per cent. of iron. It is highly valued for mixing with certain of the clay ironstones of Yorkshire, and is exported to that district at the rate of 100 tons daily.

III. *Yorkshire.* In the moorland district of Yorkshire the lower oolites, as well as the lias, contain great deposits of ironstone, the following being the principal horizons in descending order:—

A. *Upper Sandstone Shale and Coal* of Phillips, probably of the age of the great oolite. This group contains numerous bands of ironstone in nodules, some of which were worked in ancient times.

B. *Lower Sandstone Shale and Coal* of Phillips, equivalent to the upper part of the inferior oolite. It contains similar nodules to those in the upper series.

C. "*Dogger.*" This includes the lower part of the inferior oolite and the sands below it, or "Lias sand" of Dr. Wright. In Rosedale the lower part of this deposit forms a rich iron ore, often yielding as much as 50 per cent. of iron. It has the green or blue colour and the pseudo-oolitic structure of the Northampton sand when seen in the unweathered state.

D. *Middle Lias.* This formation yields the Cleveland ironstone, which is divided into several beds, separated by shale. The total thickness of ironstone rock varies from 8 feet, or less, to 20 feet, and the yield per acre from 20,000 to 50,000 tons. The whole of the workable ironstones are in the highest part of the middle lias.

The following is the return of the amount of iron ore raised and consumed in the United Kingdom for the year 1869

Districts.	Iron Ores.	Tons.
Cornwall and Devon . .	Spathic red and brown	11,723
Somersetshire . . .	Spathic . . .	27,230
Gloucestershire . . .	Brown . . .	172,023
Wiltshire	Oolitic brown . .	104,795
Oxfordshire	" " . .	10,167
Northamptonshire and Lincolnshire . . .	" " . .	793,284
Coal-fields of central England	Clay, and black band and brown .	2,323,232
Lancashire and Cumberland .	Red	1,832,237
Yorkshire	Clay band and cleveland . .	3,325,583
Northumberland and Durham	Clay band and spathic	159,500
Wales	Clay band and brown .	748,495
Isle of Man	Brown . . .	1,292
Scotland	Clay and black band .	1.950,000
Ireland	Black band and brown	65,000
Foreign ores . . .	Specular red and brown . .	131,000
	Total	11,656,241

Some of the quantities are approximations, and are probably less than the actual produce. (See mineral statistics for 1869.)

In addition to these ores there are used 192,000 tons of "Purple ore" * or residues of pyrites after the extraction of copper and sulphur, and a large proportion of the cinder produced in forges in rolling mills.

* An analysis of this ore is given at p. 449

CHAPTER IV.

ASSAY AND ANALYSIS OF IRON ORES.

In order to arrive at the economic value of an iron ore, it is requisite to determine not only its percentage contents of metallic iron, but the approximate constitution of the associated earthy matters with regard to their fusibility, and also the amount of elements likely to exert a special influence on the iron produced, such as sulphur, phosphorus, &c., which as a rule are present only in a small quantity. For the latter purpose it is necessary to make use of the ordinary processes of quantitative chemical analysis, while the two former questions may be answered by means of the dry assay, which reproduces in miniature the operations performed on the great scale in the blast furnace, giving as a result the maximum amount of cast iron to be obtained for the ore under the most favourable conditions.

If it is desired to know the amount of pure iron present, recourse must be had to the wet way, either by direct determination as peroxide, or indirectly by the volumetric method, in which the amount of metal is deduced from the number of measures of solution of an oxidising agent of a given strength necessary to convert the amount of protochloride of iron contained in the sample dissolved in hydrochloric acid into perchloride. This latter method is in many respects preferable to the former, and may be used with advantage not only in assaying, but also in the complete analysis.

The method of conducting these operations will next be briefly noticed under the following heads:—

1. Dry Assay.
2. Wet Assay.
3. Analysis.

Dry Assay. The ore in a finely divided state, mixed with charcoal and appropriate fluxes, is exposed in a crucible to a full white heat in a wind furnace or forge. The reduced iron combines with a portion of carbon, forming cast iron, while the earthy matters of the fluxes are properly adjusted to give a fusible slag.

The following method is recommended by Berthier to be used in the preliminary determination of the earthy matters:—

A weighed quantity (about 150 grains) of the ore is to be heated to redness in a platinum crucible; the loss of weight gives the amount of water, carbonic acid, and other volatile matters. Another weighed quantity, in fine powder, is heated with very weak nitric acid, which dissolves out the carbonates of lime and magnesia; the residue, after filtration, is weighed, and contains only oxide of iron, clay, and quartz, the difference giving the amount of the earthy carbonates.

Lastly, another portion of ore is digested in strong hydrochloric acid, whereby the carbonates of lime and magnesia and the oxides of iron are dissolved, while the insoluble residue consists of quartz and clay. This is weighed, and the oxides of iron are determined by the difference of weight after deducting that of the carbonates of lime and magnesia previously found. If it is desired further to determine the amount of quartz, the residue of the last operation, fused with three times its weight of a mixture consisting of equal parts of carbonates of soda and potash, evaporated to dryness with hydrochloric acid and digested with water, whereby the silica is rendered insoluble, and may be collected on a filter, dried, ignited, and weighed, the difference between it and the weight of the total insoluble residue, gives approximately the amount of alumina.

From the results obtained by the preliminary investigation, the proportion of fluxes necessary to be added can be calculated, the object being to produce an easily fusible slag. The following are good types of such slags :—

$2\ (3\ CaO.\ SiO^3) + Al^2O^3SiO^3$, with 47 lime, 15 alumina, and 37 silica per cent.

$3\ CaO.\ 2\ SiO^3 + Al^2O^3\ 2SiO^3$, with 30 lime, 14 alumina, and 56 silica per cent.

The first approximates in composition to the average slag of a coke furnace; while the second, in like manner, represents that from a charcoal furnace in good working order.

The following are the principal fluxes required :— 1. Silica in the form of white glass-house sand or ground flints, which are practically free from iron: the purest variety is that obtained by crushing and grinding rock crystal, which has been previously shivered by quenching in water from a red heat, but this process is troublesome and unnecessary. 2. Alumina: this is best supplied in the form of china clay, which contains about 40 per cent. of alumina, 47 of silica, and 13 of water. Before using it must be dried at a strong heat and finely powdered. Fire clay and shale are also used, but have the disadvantage of containing small quantities of iron. 3. Lime, either in the caustic state, or as carbonate; the latter is more convenient, either statuary marble, chalk, or any limestone free from iron may be used. It may in some instances be advantageously replaced by fluorspar, which forms a good slag, but is rarely used on the large scale in the smelting process. Plate or crown glass free from lead may be substituted for sand with argillaceous ores: it contains from 60 to 70 per cent. of silica, the remainder being lime, potash, and soda. Borax, on account of its great solvent powers, is not to be recommended, as it is liable to take up a portion of the iron which escapes reduction, causing a loss on the assay. Clean blast-furnace slags, such as are obtained from a furnace on grey iron, if carefully freed from any entangled shots of metal, may be used with advantage in fluxing rich ores containing but little foreign matters. The best slag for argillaceous ores is that resulting from a mixture of carbonate of lime equal to two-thirds of the total amount of clay present.

Although Berthier's method of approximately determining the composition of the ore previous to the assay may in certain cases be advantageous, it is not generally advisable to adopt it, as a sufficiently good idea of the nature of the fluxes to be added may usually be formed from the appearances of the ores alone. Thus, hematites, both red and brown, are generally associated with silica, and require both lime and alumina. Spathic and other calcareous ores not containing clay require an addition of silica in the form of sand, or an acid silicate such as glass, besides lime and alumina, while argillaceous carbonates may be fluxed with lime alone. In Sweden, magnetic ores are usually assayed with reference to their self-fluxing powers, those varieties that contain a sufficiency of readily fusible earthy minerals, such as garnet, idocrase, pyroxene, &c., to form their own slags, being of greater value than those requiring the addition of fluxes.

The proper apportionment of fluxes may also be formed by the method of trial and error, three or four equal weights of the ore being treated at the same time in the furnace with variable additions, according to the following list:—

	I.	II.	III.	IV.	V.
Silica . . .	50	50	30	45	15
Alumina . . .	25	16	20	18	5
Lime . . .	25	34	50	37	80

The weight in all cases to be made up to one-half of that of the quantity of ore employed. The most advantageous proportion will of course be that giving the highest produce.

The following proportions of fluxes are recommended by Plattner:—

	I.	II.	III.	IV.	V.
Lime . . .	10	5	25	20	—
Fluorspar . . .	25	25	25	20	20
Clay . . .	—	—	—	—	10

No. I. is for use with magnetite; II. with specular iron ore; III. with earthy and siliceous red and brown hematite, clay iron ore, and limonite; IV. with brown hematite and forge cinders; and V. with spathic ore.

Mode of Conducting the Assay. This may be performed either in plain clay crucibles, or in such as have been lined with charcoal or *brasqued.* In the former case, from 100 to 150 grains of finely-powdered ore are intimately mixed with the appropriate fluxes and about 25 per cent. of charcoal powder, and charged into a blacklead or clay crucible, the cover being luted on with clay. It is then placed in a wind furnace, and subjected to a moderate heat for a short time, in order to drive off any water and carbonic acid that may be present, after which the fire is increased and maintained at a full white heat for an hour. When the fuel has burnt down, the crucible is taken out and allowed to cool. It is then broken, and if the operation has been properly conducted, a button of grey cast iron, smooth and well melted, will be found at the bottom, surmounted by a well-melted glassy or enamel-like slag. It is, however, necessary to reduce the slag to powder and examine it with a magnet for shots of metal, which are to be added to the principal button and weighed with it. If the fluxes have been improperly proportioned, the slag will be only imperfectly melted, and the assay must be repeated.

The use of brasqued crucibles is generally preferable to the foregoing method. They are prepared as follows:—The hollow of the crucible is filled with charcoal powder rammed down hard, and rendered adhesive by a slight admixture of treacle or starch. When dry, the cement is carbonised by heating to redness in a covered vessel, and a compact smooth mass of charcoal is obtained, exactly filling the crucible. A cylindrical cavity, of sufficient size to contain the mixture of flux and ore, is bored out with a spatula, and the sides are polished by rubbing with a glass rod. After the introduction of the assay the hole is stopped with a charcoal plug, and the cover of the crucible is luted on as before described. The weight of samples operated upon may be, as in the former case, from 100 to 150 grains.

A more convenient method of conducting the assay is that adopted in Sweden, where small brasqued crucibles, about 2 inches high and 1½ inches in diameter, are used. The weight of ore taken being only 10 or 15 grains, four crucibles are placed in the furnace at one time, a piece of fire brick about 3 inches square being used as a stand: coke or anthracite may be most conveniently used as fuel. As soon as a white heat has been attained, the fire is allowed to go down, and the crucibles are removed by lifting out the stand, to which they are generally cemented by the slag of the fuel when sufficiently cool. When cold they are broken, and the buttons of metal and slag found in the cavity of the brasque are removed and separated, the latter are crushed in a steel mortar, and any further portions of iron that they may contain are extracted by the magnet in the usual way.

When the assays are well done the four results should not vary from each other more than two or three-tenths per cent.

The following conclusions may be deduced from the appearance of the slag:—If it is perfectly transparent and of a green tint, silica is in excess; if a light grey or bluish enamel, or translucent glass, the earthy bases, lime and alumina, are in proper proportion; but if stony and rough, or crystalline in fracture and dull in lustre, it is too basic.

If the product, instead of being melted, is only fritted, and contains the reduced iron interspersed as a fine grey powder, both silica and alumina are deficient in the flux, lime and magnesia being in excess. The latter is one of the most refractory substances found in iron ores, and, where present in quantity, requires an addition of both silica and lime.

A vesicular slag, with the iron interspersed in malleable scales, indicates the presence in the ore of silicates of iron and manganese, or an excess of silica, which react on the carburetted iron as it forms, producing malleable iron and carbonic acid; the latter gas escaping through the slag, gives it a spongy character. This defect is to be corrected by the addition of lime.

Manganese, when in small quantity, gives the well known amethystine tint to the slags; in larger proportion it renders them yellow, green, or brown. The duller colour is said to be due to the formation of sulphide of manganese.

The fracture of the button obtained in the assay presents indications of the presence of foreign bodies much in the same way as that of pig iron produced on the large scale. Thus a hard brittle white metal contains phosphorus; sulphur produces a strong, reticulated, mottled structure; manganese a bright crystalline character, resembling spiegeleisen; titanium a duller grey, reticulated texture; while a dark grey graphitic metal shows that the ores are easily reducible, or that a very high temperature has been obtained in the furnace. No exact information as to the quantitative composition of the iron likely to be produced from the ore on the large scale can, however, be directly obtained from the assay, as the conditions under which it is performed—the ore and fluxes being in a state of intimate contact, and the quantity of fuel unlimited—represent a favourable combination of circumstances totally unattainable in the smelting furnace.

Wet Assay. When bichromate of potash, dissolved in water, is added to the acid solution of a protosalt of iron, the latter is converted, at the expense of the oxygen of the chromic acid, into a persalt, with the simultaneous production of a potash salt, a sesquisalt of chromium, and water. The following expresses the reaction with protochloride of iron dissolved in hydrochloric acid:—

$$6\,\mathrm{FeCl} + 7\,\mathrm{HCl} + \mathrm{KO}\ 2\,\mathrm{CrO^3} = 3\,\mathrm{Fe^2Cl^3} + \mathrm{KCl} + 7\,\mathrm{HO} + \mathrm{Cr^2Cl^3}.$$

When a solution of permanganate of potash is substituted for the bichromate, the formula becomes—

$$10\,\mathrm{FeCl} + 8\,\mathrm{HCl} + \mathrm{KO.Mn^2O^7} = 5\,\mathrm{Fe^2Cl^3} + \mathrm{KCl} + 8\,\mathrm{HO} + 2\,\mathrm{MnCl}.$$

The termination of the reaction can in either case be easily determined. The permanganate solution is of a deep rose-red colour, which is entirely discharged as long as any protochloride remains unaltered; but the smallest drop in excess, owing to its strong colouring power, communicates a decided pink tint to the assay.

With bichromate of potash an indirect method must be employed, as the change of colour is not sufficiently marked to indicate the moment of complete peroxidation of the iron. For this purpose, a very weak and nearly colourless solution of ferricyanide of potassium, or red prussiate of potash, is used, which produces a bluish-green tint when mixed with protosalts, but is unaltered by persalts of iron.

If in the above experiments the oxidising solutions be made of a known strength, and be supplied from graduated glass vessels, the cubic volume consumed in either case will furnish us with a ready method of computing the amount of iron contained in the solution operated upon.

According to the laws of chemical proportions, 151 grains of bichromate of potash correspond to 168 grains of iron in the first of the above formulæ, and 158 grains of permanganate of potash to 280 grains of iron in the second, or 0·898 grains of the former and 0·564 grains of the latter salt are respectively equivalent to 1 grain of pure iron.

Both of the above methods are used in practice; they are known after the names of the chemists who introduced them—the permanganate process as Marguerite's, and the bichromate as Penny's process. The latter, although somewhat the more complicated, owing to the use of the second test solution, is perhaps the more generally useful of the two, its indications not being unit measures, will exactly correspond to 10 grains or other unit weights of metallic iron, so that the percentage of the ore may be found directly from the number of measures consumed without the trouble of calculation. The necessary proportions are 315 grains of bichromate or 197 grains permanganate to half a gallon of distilled water. The latter solution must be carefully kept from contact with organic matter in a glass-stoppered bottle. That of the bichromate is more stable, and can be preserved for a long period without alteration if protected from evaporation.

When greater accuracy is required, as, for example, in analytical determinations, solutions of half the above strength, 1,000 measures, corresponding to 5 grains of iron, are to be preferred.

The red prussiate solution required in Penny's process, must be very weak, from 2 to 3 grains being sufficient for half a pint. It is used in small spots, which are dropped on a white porcelain slab from the end of a glass rod. A drop of the solution under assay is conveyed to the slab in a similar manner, and mixed with one of the spots, when a blue tinge will be produced as long as any unaltered protosalt of iron remains. The addition of the standard solution must therefore be continued, testing by drops at short intervals, until the yellowish colour of the prussiate spots can no longer be changed.

When large quantities of standard solutions are kept, it is necessary, from time to time, to readjust them, or, what is preferable, to determine their absolute value. This is done by dissolving a weighed quantity—say 10 grains—of bright iron pianoforte wire, which may be considered as containing 99½ per cent. of iron, in hydrochloric acid, and observing the number of measures requisite to convert the protochloride of iron into perchloride in the manner already described. The value so found is to be applied in computing the assays instead of the assumed standard. Crystallised protosulphate of iron, $FeO. SO^3 + 7 HO$, or protosulphate of iron and ammonia, $FeO. SO^3 + NH^4O. SO^3$, salts soluble in water, may be used for the same purpose. The latter salt has the advantage of containing exactly one-seventh of its weight of iron.

Solution of the Ore. This may be conveniently effected in the conical flat-bottomed glass flasks used by gold assayers. A weighed quantity, from 10 to 20 grains, of the ore in a state of fine powder is digested with strong hydrochloric acid at a moderate heat for about half an hour. Some varieties of hematite and magnetite are very difficultly soluble in hydrochloric acid, but can be rendered so, by a preliminary reduction to the metallic state, by heating to redness in an atmosphere of hydrogen or coal-gas.

When the iron is completely dissolved, any portion of it existing as perchloride must be reduced to the state of protochloride by the addition of metallic zinc, and boiling till the liquid no longer shows a yellow tint.

Sulphite of soda may be used for the same purpose, but care must be taken to remove any free sulphurous acid by boiling until the gas is no longer perceptible by its peculiar smell. In either case, the solution must be diluted with water before the application of the reducing agent.

Determination of the Iron. The contents of the flask, when cooled, are to be transferred to a porcelain dish, and the standard solution is then added from a graduated tube or burette, the liquor being well stirred after each addition, the termination of the reaction being indicated by the coloration tests already described.

Blackband ores dissolve in acid with separation of finely-divided carbonaceous matter, which must be removed by filtration if the assay is to be made by the permanganate process, care being taken to prevent peroxidation of the iron by exposure to the air, by covering the funnel with a glass plate, keeping a piece of zinc on the filter, and washing rapidly with hot water. When the same ores are assayed by Penny's process, the filtration, though not obligatory, is to some extent advantageous, as the dark-coloured suspended particles interfere with the exact determination of the end of the decoloration.

Zinc cannot be used in the reduction of the solutions obtained from ores containing titanic acid, as it converts the perchloride of titanium, $TiCl^2$, into the sesquichloride, Ti^2Cl^3. In such cases sulphite of soda is to be employed.

The amount of iron existing as protoxide in a mixed ore, such as magnetite, may also be determined by the volumetric method. The process is exactly similar to an ordinary assay, except that the reduction with zinc or sulphite of soda is omitted, the amount of protochloride formed being in equivalent proportion to that of protoxide contained in the ore. Care must be taken to exclude air during the operation. If a second determination of the total quantity of iron be then made, the amount of peroxide may be calculated from the difference of the two. This plan only gives correct results when no oxidising agents, such as peroxide of manganese, are present. As in the latter case, chlorine is evolved during the solution in hydrochloric acid, or the protochloride of iron is converted into perchloride.

Comparative Yield of Dry and Wet Assays. As the return of the dry assay is made in cast iron, a substance which, as has already been stated, is of very variable composition, containing at times as much as 16 per cent. of other elements, while the wet assay expresses the amount of pure iron in the ore, the results obtained by the former method should in all cases indicate a higher percentage than the wet assay of the same ore. Such an excess is actually observed in practice when the fluxing has been properly conducted, and the assays have been exposed to a sufficiently high temperature. The difference is greatest with those spathic ores that contain a large quantity of carbonate of protoxide of manganese, as a considerable portion of the latter metal is likely to be reduced and alloyed with the iron, giving rise to the variety of metal known as spiegeleisen. With ordinary ores, however, the difference is not so great, the excess being exactly from 2 to 4 per cent. The composition of the assay buttons cannot, however, be directly paralleled with that of the pig iron likely to be obtained from the same ores on the large scale, as the conditions are dissimilar in many important particulars. Thus the assay is conducted with a practically unlimited quantity of reducing material, and the ore and flux are in the finest possible state of division, and intimately mixed, so that the reduction may take place under the most favourable circumstances, and such as are not always obtainable in the blast furnace. Except, therefore, when conducted as fluxing experiments, the results of the dry assay are less valuable than those obtained by the wet assay, which is in all cases to be preferred when it is desired to ascertain the exact percentage of iron contained in the ore.

The following series of dry assays of magnetic ores, compared with corresponding analytical determinations of the iron, show a different result, the assays in almost all cases giving a lower produce. The method adopted was a somewhat dissimilar one from that usually employed, as the ores were reduced either without flux, or with at most 5 per cent. of lime.

	I.	II.	III.	IV.	V.	VI.	VII.
Iron by dry assay	59·0	58·0	66·0	66·0	58·0	59·0	71·0
,, analysis .	60·9	59·6	66·6	67·8	59·6	61·2	65·6

The chief cause of these differences is to be sought in the more perfect fusibility of the earthy matters in some of the samples. The whole number were crystalline magnetites, associated with hornblende, chlorite, carbonate of lime, and quartz from the Roslagen district, in Sweden.

Analysis of Iron Ores. The following sketch of the processes followed in the systematic analysis of iron ores is derived from the "Memoir on the Iron Ores of Great Britain," founded on an elaborate investigation of English and Welsh iron ores, conducted by Messrs. Dick and Spiller in the laboratory of the Royal School of Mines, under the direction of Dr. Percy, published in part between the years 1856—62.

The chief components determined in the analysis of iron ores for metallurgical purposes are estimated in the following order:—

1. *Insoluble Matter.* A weighed quantity of the ore finely powdered is digested in strong hydrochloric acid until no further action takes place, and then boiled for fifteen minutes before dilution. The insoluble portion is then separated by filtration, and after having been well washed with boiling water, is dried, separated from the filter, ignited to redness, and weighed. Its subsequent treatment will be described further on.

2. *Hydrochloric Acid Solution.* After peroxidisation of iron by nitric acid, or chlorate of potash when necessary, the filtrate from No. 1, rendered nearly neutral with ammonia, is boiled with an excess of acetate of ammonia, and filtered hot. The precipitate is washed with hot water. The filtrate is received in a flask rendered alkaline with ammonia, and after the addition of a few drops of bromine is carefully corked, and allowed to stand for twenty-four hours. It is then heated and rapidly filtered. The precipitate of hydrated peroxide of manganese is, on ignition, converted to mangano-manganic oxide, $Mn^3 O^4$. The filtrate from the last operation contains lime and magnesia; the former is precipitated by oxalate of ammonia, and is either weighed as carbonate, or sulphate: it is converted into the former by ignition, or into the latter by moistening with sulphuric acid, and heating until the excess of acid is driven off. The filtrate from the precipitated oxalate of lime is heated with phosphate of soda and excess of ammonia, and allowed to stand

for twenty-four hours, during which time a granular precipitate of phosphate of magnesia and ammonia separates. This is collected on a filter, and as it is sensibly soluble in pure water, must be washed with water containing a little ammonia. By ignition, the precipitate which has the composition $(2\,MgO.NH^4O.)PO^5$ loses its ammonia, and is converted into bibasic phosphate of magnesia, and may then be weighed, and the amount of magnesia computed.

The first precipitate produced in the hydrochloric acid solution, consisting of basic acetates of iron and alumina and phosphoric acid, is to be dissolved in hydrochloric acid, and boiled with excess of caustic potash in a platinum, or what is preferable, a gold basin. Both peroxide of iron and alumina are at first precipitated by this treatment, but the latter oxide subsequently redissolves, and is separated by filtration. The filtrate is acidified with hydrochloric acid, and boiled with an addition of chlorate of potash for the purpose of destroying any soluble organic matter due to the action of the caustic alkali on the filter paper, nearly neutralised with ammonia, and finally rendered alkaline with carbonate of ammonia, when the alumina, with some phosphoric acid in combination, goes down in an insoluble form, and is collected and weighed after washing and ignition. The amount of phosphoric acid is determined by a special process, and deducted from the former weight: the difference gives the corrected amount of alumina.

The precipitate of hydrate of peroxide of iron remaining after separation of the alumina usually contains a small quantity of silica, and is therefore not subjected to any further treatment, as the amount of iron may be more accurately determined by standard solution of bichromate of potash in the manner already described for the wet assay.

Determination of Phosphorus. A weighed quantity of the ore is digested with hydrochloric acid, and filtered from the insoluble residue. The filtrate, which should not be too acid, is treated with sulphite of soda to reduce the iron to the state of protochloride, nearly neutralised with carbonate of soda, acetate of soda is added in excess, and the liquid boiled. A strong solution of perchloride of iron is then added until the precipitate formed has a decidedly red colour. This precipitate, which contains all the phosphoric acid present in the ore, is, after filtration and washing, dissolved in hydrochloric acid, tartaric acid and ammonia being added to the solution to prevent the precipitation of the iron. The phosphoric acid is then separated as phosphate of magnesia and ammonia by the addition of chloride of ammonium, sulphate of magnesia, and ammonia, care being taken to conduct the operation in the manner already described for the determination of magnesia.

Determination of Sulphur. This may exist under two different conditions in the ore, either as soluble sulphates, or sulphides decomposable by hydrochloric acid, or as bisulphide of iron, which is not affected by that reagent. For the determination of the sulphuric acid, the solution obtained by digestion of a weighed quantity of the ore in hydrochloric acid is treated with chloride of barium, with the production of an insoluble precipitate of sulphate of baryta, which is collected on a filter, and estimated apart. Iron pyrites, if present, will be found in the insoluble residue, which is to be fused with nitre and carbonate of soda in a gold crucible. The fused mass is then dissolved in hydrochloric acid, evaporated to dryness, redissolved, and filtered from the insoluble residue. The sulphuric acid formed by the oxidising action of the nitre on the pyrites will be found in the last filtrate, and is precipitated by the addition of chloride of barium as before: 100 parts of sulphate of baryta correspond to 34·37 of sulphuric acid, 25·48 of iron pyrites, or 13·75 of sulphur.

Analysis of Insoluble Residue. The examination of the residue insoluble in hydrochloric acid, is not usually carried out in commercial analysis, being generally returned as "insoluble siliceous matter;" it is, however, more satisfactory to determine its composition, as without a complete analysis, an element of value in the working of the ore, namely, the presence of easily fusible earthy silicates, such as garnet, hornblende, &c., may be overlooked. The residue from the first operation must be fused with four times its weight of carbonates of soda and potash mixed in equal proportions; the fused mass is then dissolved in dilute hydrochloric acid, evaporated to dryness, the residue moistened with strong hydrochloric acid, and after standing for some hours, digested with hot water and filtered. Silica and titanic acid are rendered insoluble by this treatment, while the filtrate contains all the alumina, iron, lime, and magnesia that may be present, which are to be separated by the methods already described.

If the precipitated silica contains titanic acid, it may be separated from it, by mixing with sulphuric acid, and exposure in a platinum dish for several hours to the action of hydrofluoric acid in a closed lead chamber, when the silica volatilises, leaving a residue, consisting mainly of titanic acid, in addition to small quantities of alumina and peroxide of iron.

The examination for titanic acid is a difficult and troublesome process, as a certain quantity is usually dissolved by hydrochloric acid, goes down with the iron in the analysis of the soluble portion, and can only be rendered insoluble by ignition. In like manner, in the treatment of the insoluble residue, a portion goes into solution unless the fused mass be strongly heated before re-dissolving.

Determination of Water. The accidental or hygroscopic moisture is found by exposing a weighed quantity of the ore in powder to a heat not exceeding that of boiling water, and re-weighing to determine the loss. For combined water the dried residue is placed in a hard glass tube, to which is adapted a weighed tube containing fragments of fused chloride of calcium. The powder is then gradually raised to a low red heat, whereby water and other volatile matters in combination are expelled; but of these, only the former is absorbed by the chloride of calcium, so that its amount may be found directly by re-weighing the tube.

Determination of Carbonic Acid. This may be effected by decomposing a weighed quantity of the ore with sulphuric acid in a small flask provided with a delivery tube, carrying the gas into a second flask containing strong sulphuric acid, which absorbs any water carried over. Carbonic acid only escapes, and is determined by the loss of weight of the apparatus.

The preceding are the principal substances usually determined in analyses for metallurgical purposes. The complete operation is both difficult and tedious, involving numerously repeated precipitations, filtrations, and washings, and, in some cases, requiring between thirty and forty determinations of weight in the examination of a single ore. The advantages to be gained from such analyses are, however, very great, especially in the case of new or unknown minerals, which are not generally adopted in the smelting process without preliminary chemical investigation.

The analyses of cast and wrought iron and steel are conducted in a particular manner, and will be noticed after the description of the processes by which these metals are obtained.

CHAPTER V.

PREPARATION OF IRON ORES.

In England it is not usual to subject iron ores to any complex mechanical treatment or dressing, such as is usual with the ores of other metals, as the low price of workable ores, together with the facility for obtaining supplies, renders it almost impossible to improve poor or inferior ores advantageously. But on the Continent, in many parts of France, Belgium, and Germany, argillaceous brown iron ores of low produce are separated from a portion of the intermixed clay and sand by sifting, crushing, or stamping, and washing. This is more especially the case with the lenticular or pisolitic ores of the oolitic and cretaceous formations (bohnerz). As the chief object is, however, to remove such finely-divided matters as can be carried away by a stream of water from the larger masses of ore, the breaking machinery must be so combined as to produce the smallest amount of dust. Roller-crushing mills are therefore to be preferred to stamps. Irregular hollow nodules of brown iron ore, such as found in the Greensand formation, and other sandy limonites, may be separated from the adherent sand by dry-sifting; and by cracking the nodules, a further portion of loose sand will often fall out of the interior.

The machinery used for washing iron ores is generally of a very simple character. The commonest arrangement consists of a horizontal shaft, armed with projecting knives or paddles, revolving in a cylindrical trough, through which a stream of water is kept flowing. The rough ore, after being well mixed up with the water by the action of the paddles, is carried by the stream into a settling launder or pit, where the heavier masses of clean ore deposit, while the finely-divided earthy matter is carried off with the waste water. When fine-grained soft ochreous ores are subjected to washing, a large quantity of finely-divided hydrated peroxide of iron is liable to be carried off by the stream, together with the clay. In such cases it is necessary, if it is desired, to avoid a considerable loss of iron, to collect the slimes in catch-pits, and subject them to further treatment. An instance of this kind is furnished in the preparation of the ores produced at the Cornelia mine, near Stolberg, in Rhenish Prussia, where argillaceous yellow ochreous ore, after a preliminary spalling or breaking by hand, is subjected to the action of a vertical rotating agitator in a circular trough, through which a constant current of water is kept flowing. The fine muddy particles are removed by the stream, while the ore remaining behind is thrown on to an iron riddle, and the small pieces falling through are washed in a slightly inclined plane in a stream of water. The slime, together with that from the former operation, is carried into settling pits, and deposits a ferruginous mud, which, when sufficiently dry, is moulded into bricks and burnt, yielding a product containing from 40 to 43 per cent. of iron. The production is about 25 tons per day of twelve hours, at a cost of 17*s.*, or 7¾*d.* per ton, for washing. It is obvious that the above process is not susceptible of being applied to any great extent, a certain binding quality being necessary in order to give bricks of sufficient cohesive strength to withstand the crushing effect of a high blast furnace. This difficulty has hitherto prevented the smelting of certain finely-divided ores of high percentage, such as the magnetic and titaniferous iron sands of New Zealand and the St. Lawrence coasts of Labrador, as, if used alone, they either stop the draught of the furnace altogether, or are blown out at the throat, if the blast be increased to overcome the obstruction. Various plans have been proposed for mixing these sands with clay or other binding materials, but hitherto without success, on account of the great expense when compared with the value of the product obtained, whose price will of course be measured by the local cost of ores fit for smelting without preparation.

In Belgium the washing of iron ores is conducted in inclined cylindrical drums of cast iron, 32 inches diameter, and 6½ feet long, armed internally with projecting spikes, which are made to rotate, while the ore is fed in at the upper end, a stream of water passing through at the same time. The particles of ore and clay loosened by the tearing action of the spikes, are discharged at the lower end into a trough, where they are separated by a current as in the preceding instances. In Wurtemberg and Baden pisolitic brown iron ores contained in a ferruginous and calcareous marly matrix are cleaned by the method of jigging, hand sieves, of one-twelfth of an inch aperture, being employed, which are subjected to a gyrating motion in a tub of water. The cleaned grains of larger size remain on the sieve, while the fine stuff sinks in the tub, depositing a second quality of ore or hutchwork in the tub: the waste slime is allowed to run off by a hole near the bottom. By the adoption of some of the newer forms of jigging machinery this process may be made continuous in its action, but only by an increased consumption of washing water, and corresponding loss of material, to which must be added the interest on capital and cost of maintenance of machinery. In most cases, therefore, it will be found preferable to work in the furnace with ores of lower produce, when they are not inadmissible from excess of actually deleterious ingredients, such as iron pyrites, phosphate of lime, &c., rather than to concentrate them by mechanical means to a higher produce. An example of this is furnished by the magnetiferous dolerite of Taberg in Sweden, containing from 25 to 30 per cent. of iron. This, when concentrated by dressing to 43 per cent., gave a product which, on account of its finely divided state, worked so badly in the furnace, that it was found to be better to smelt it in its natural condition, the expense due to the increased consumption of fuel being compensated by greater facility in treatment.

Weathering. The argillaceous ores of the coal measures occurring in nodules, are often difficult to separate from adherent fragments of shale when first raised; if, however, they be exposed to the action of the air for some time, superficial oxidation takes place, the shale disintegrates, and can readily be removed. In like manner, ores containing sulphides, such as copper, iron, and magnetic pyrites, when exposed to atmospheric air and moisture, give rise to soluble sulphates which may be partially removed by rain. The beneficial effect of this process, which applies more particularly to spathic ores, may be increased by watering the heaps during dry weather, for the purpose of washing out the soluble salts formed, also turning them over to expose fresh surfaces from time to time. In the Harz, hard silicated ores are subjected to this treatment for a period of several years before smelting, but such a course could only be followed in works where the yield is comparatively small. Spathic ores, at the same time, undergo a superficial alteration by exposure, being converted into brown hematite. The same change takes place in a slight degree with nodules of clay iron ores, especially such as contain no carbonaceous matter. In all cases where ores are allowed to weather, care must be taken not to push the process too far, as in some instances absolute disintegration into small fragments or powder ensues, if the exposure be continued for too great a length of time. This remark applies specially to ores containing carbonate of lime, which, if exposed to the air for any length of time after calcination, fall to pieces, on account of the slacking of the caustic lime, produced by the decomposition of the carbonate in the roasting kiln. Such ores should, therefore, be carefully covered if not required for immediate use in the blast furnace.

At Ilsenberg, in the Harz, pyritic and siliceous hematite and magnetite, after crushing and washing, are exposed to the air for a period of from two to three years, in heaps from 2 to 3½ feet high, during which time they are repeatedly washed with water. Afterwards they are again passed through the crusher, and exhausted with water during a whole summer season, if pyrites exist in quantity. At Altenau, ores of a similar character are prepared by laying out in the air for one year, without the addition of water, after coming from the roasting kiln.

At Golrad, in Styria, spathic ores are exposed to the weather for a period of five years before being delivered to the smelter, during which time the amount of sulphur is reduced from 3·68 to 0·20 per cent.

The presence of carbonate of lime in these ores is a great obstacle to the removal of the sulphur by the action of water after roasting, as the caustic lime formed, decomposes the sulphates of iron and copper with the production of gypsum and hydrated oxides, or basic sulphates, which latter are insoluble in water, and cannot, therefore, be removed by mere washing. The same is true of the gypsum, which although soluble, is not to the same extent as the sulphate so, whose expense it is formed.

According to Lüders, from 2 to 3 per cent. of lime and magnesia in a spathic ore is sufficient, when the sulphur does not exceed from 0·3 to 0·5 per cent., to combine with the sulphuric acid, and to decompose the sulphate of copper formed by roasting—four parts of sulphur combining with seven of lime to form gypsum. With larger amounts of pyrites, when the quantity of sulphur is increased to 1·2 per cent., the lime and magnesia are only sufficient to take up the sulphur set free by roasting, while the sulphate of copper formed remains undecomposed, and can be removed by washing with water. These reactions are sufficient to account for the common presence of copper in pig iron smelted from spathic ores.

The removal of phosphoric acid from iron ores by means of hydrochloric acid after roasting has been tried, but cannot be done to profit. Sulphurous acid is used for the same purpose at Kladno, in Bohemia—it is said with successful results.

Ironstone Breakers. In order to attain the greatest regularity in working blast furnaces, it is advisable that all charges of ores and fluxes should be reduced to fragments of nearly uniform dimensions. The size of the fragments should be proportioned to the height of the furnace, and the greater or less susceptibility or reduction of the ore. Thus in large furnaces, such as those of the hematite districts in Lancashire, it is found convenient to break both ore and fluxes to the size of ordinary road metal, or cubes from 1½ to 2 inches in the side. In Sweden, hard magnetic ores, after roasting, are crushed to about ¾ to 1 inch cubes. The Cleveland furnaces, as a rule, take the ore in much larger blocks, often as much as 4 or 6 inches in the side. The limits in either direction are to be determined by a comparison of conditions, which are different in each district, the larger masses being only adapted for tall furnaces, where, by the slow descent of the charges, sufficient time is allowed for the heat to penetrate to the interior, at the same time that a free passage is afforded to the upward current of gases. Smaller pieces, on the other hand, although exposing a greater surface to the action of the reducing gases, pack closer together, and offer greater resistance to the blast.

The reduction in size may be effected either by manual or mechanical means; but there are probably very few iron-making districts in the world where the former method can be applied at the present day, unless it is requisite to combine the breaking with hand-picking in the removal of injurious substances, such as heavy-spar, &c. Of the various mechanical methods of breaking, the most advantageous are roller crushers, and the new lever machine, known as Blake's rock breaker. Tilt or other forms of lever hammers may also be used, while stamps are in most cases objectionable, except with very hard ores, from their pulverising action, producing a proportionably larger quantity of dust. This may, to a certain extent, be avoided by substituting a grated floor for the stamp-heads to work upon, instead of the ordinary solid bed, so that the fragments, as soon as they are broken sufficiently small, fall through the spaces between the bars, without being subjected to an unnecessary amount of pounding.

At Finspong, in Sweden, a tilt-hammer, striking 60 blows per minute, breaks from 15 to 16 cwts. per hour to ¾ inch size. The ores are magnetite and specular schist, which have been previously roasted.

Crushing Rollers are used to a considerable extent for breaking iron ores, having the advantage of producing fragments of a tolerably uniform size without much dust. It is essential, however, that the material operated upon should not be too hard; they are therefore better adapted for roasted than raw ores. As an example of a large ironstone crusher of this form may be mentioned that at Eisenerz, in Styria, employed for breaking spathic ores after roasting. It has a single pair of rolls, 18 inches in diameter and 12 inches wide, whose bearings are carried on spring beams, which allow a certain play to the rolls, in case of the resistance being increased by the introduction of lumps of raw stone by mistake. The rolls, being set to a distance of about 1½ inches, receive the roasted ore in lumps of from 20 to 30 cubic inches, and deliver it at a maximum size of 4 to 5 cubic inches, from 1½ to 1¾ inch cube. When making 36 revolutions per minute, the amount passed through per hour is about 40 tons; but increasing the opening to 1¾ inches and the number of revolutions to 40 or 42, from 60 to 75 tons may be broken in the same time, the amount of power expended in either case being 19 and 24 horse power respectively.

Blake's rock breaker resembles an ordinary pair of nut-crackers, supposing one jaw to be fixed to a vertical framing, while the opposite one receives a reciprocating motion about its hinge. This is effected by means of a powerful combination of levers actuated from a rotating shaft. The faces of the jaws are corrugated into shallow V-shaped grooves, placed in parallel vertical lines. At every revolution of the crank, the movable jaw advances about ⅜ of an inch toward the fixed jaw, and returns. During the latter part of the stroke, the stone grasped between the two jaws falls into the space provided by the withdrawal of the movable one, and receives and is subjected to an intense grinding pressure at the next bite, and so on until it is broken sufficiently small to pass out at the bottom. At the Kirkless Hall iron works, near Wigan, one of these machines, of 20 inches breadth of face, and capable of taking in stones not exceeding 7 inches in thickness, making from 200 to 250 revolutions per minute, breaks up red hematite ore and limestone for the furnaces at the rate of between 10 and 12 tons per hour. The size of the fragments delivered is about 1½-inch cube. A larger machine of the same construction, with a top aperture of 20 inches broad and 10 inches wide, used entirely for crushing limestone, requires 15-horse power to drive it.

At Wyandotte iron works, near Detroit, and all the charcoal furnaces on Lake Superior, the same machine is used for breaking the hard red slaty hematite noticed at p. 66 as occurring in the Huronian rocks, near Marquette. This is a very intractable material, as it combines both hardness and toughness in a high degree. The lower corners of the movable jaw are often broken off during the crushing. The crushing faces are movable, so that they can be replaced when worn out or broken. The greatest durability is obtained by the use of a metal composed of strong mottled iron, with a proportion of Franklinite spiegeleisen, the wearing surfaces being strongly chilled.

CHAPTER VI.

ROASTING OR CALCINATION OF IRON ORES.

WITH the exception of massive red hematite and certain varieties of magnetite, it is usual to subject all kinds of iron ores to the process of roasting before smelting. The advantages gained by this operation are of two kinds: the amount of iron is concentrated into a smaller weight by the removal of water, carbonic acid, and other volatile matters; and, as the fragments of mineral retain their form, they are rendered porous and more readily susceptible of being changed in the subsequent operations in the furnace. Another object is the decomposition of sulphides, such as iron pyrites, &c., which are altered by heating in an oxidising atmosphere to oxides, the whole of the sulphur being volatilised if the temperature be sufficiently high. Protoxide compounds, such as the protocarbonate of iron, absorb oxygen, and are partially peroxidised, with the production of magnetic oxide. The same change takes place in a less degree with magnetite, the hard black Swedish varieties, after calcination, occasionally presenting an outer red crust of peroxide. This absorption of oxygen, though to a certain extent disadvantageous when considered in reference to economy of fuel, as peroxide of iron requires a greater quantity of carbon for its reduction to the metallic state than the protoxide, has an important practical advantage, as the higher oxide is almost indifferent in its relations to silicas at high temperatures, while the protoxide enters readily into combination under similar conditions, with the production of a highly basic slag, which can only be reduced to the metallic state with difficulty.

The various methods of roasting iron ores may be classified under three different heads, namely :—

1. Roasting in clamps or piles in the open air
2. Roasting in the open air, the heat being confined between walls.
3. Roasting in furnaces or kilns.

The first of the above methods is principally used in localities where fuel is cheap when compared with the price of labour, but is in many respects disadvantageous, on account of the waste of fuel and the imperfect distribution of the heat, the interior of the piles often being heated to excess, with a partial fusion of the ore, when the outer parts have only attained the proper temperature.

In Staffordshire and South Wales clamps are effected in the following manner :—A bed of coal, a few inches in thickness, is laid upon a level surface, and covered with a layer of ironstone from 10 to 12 inches in depth ; this is succeeded by fresh layers of coal and stone, till the pile has reached a height of 4 or 5 feet. The heap is then lighted at the bottom, and continues to burn until the whole of the fuel is consumed. If the fire should come to the surface too rapidly, the draught must be checked by damping the spot with small ore or ashes, otherwise a partial fusion may take place, and the lumps of stone become clotted together. About 2½ cwt. of small, and ½ cwt. of large coal are consumed per ton of ore roasted. The loss of weight is from 28 to 33 per cent., an amount that is made up of the water and carbonic acid driven off, diminished by the oxygen taken up in the conversion of the protoxides of iron and manganese into magnetic oxides.

Blackband ironstones usually contain sufficient carbonaceous matter to effect the roasting without any additional fuel: a layer of coal slack is, however, generally placed at the base of the pile to start the combustion. In Scotland and Staffordshire the piles are usually made of a trapezoidal form, 3 to 9 feet in height. The smaller dimensions are to be preferred for the more highly carbonaceous ores, in order to avoid the production of too high a temperature. The spathic carbonaceous ores, known in South Wales as coal-brasses, appear to be peculiarly liable to fusion in calcination, although containing neither sulphur nor silica, from the production of a fusible ferrite of magnesia, $MgO + Fe^2O^3$.

In Westphalia, blackband is roasted in heaps 120 feet long, 30 feet broad, and 4 feet high, enclosed between walls built up of the larger lumps, small square openings being left at intervals of 12 feet along the sides. These draught-holes communicate with passages 3 feet deep in the interior of the heaps, which are filled with wood. Small ore is heaped against the sides of these passages, and the larger blocks are placed towards the middle, in order to guide the flame as much as possible into the heart of the pile. After the wood has burnt down, and the heap is fully ignited, the wall is pulled down, and the *débris* are thrown upon those places where the fire shows a tendency to come to the surface too quickly; in order to damp it. A heap of the above dimensions, containing from 500 to 700 tons, takes about a month to burn out.

When pyrites and coaly matter are present in large quantities, the heaps are only made 2 feet high, in order to prevent fusion in the interior; in such cases the lumps nearest the surface do not become sufficiently heated. In order to finish the roasting, therefore, a second layer, of 2 feet in thickness, is placed above the first as soon as combustion ceases, while the pile is still hot; and, in some cases, a third after the second has burnt out, the fire being started in the additions by a few pieces of firewood, upon which red-hot masses of ore are shovelled. If the roasting does not proceed uniformly the hottest places are checked by damping with small ore, while those that are cold and black are started afresh by digging a hole in the pile, and filling it up with red-hot stones from below. The loss of weight varies, with the amount of carbonaceous matter in the ore, from 25 to 50 per cent.

Grundmann recommends that the heaps should be covered with a coating of small ores when they contain much pyrites, in order to condense the sulphur volatilised without oxidation, in consequence of the reducing atmosphere produced by the combustion of the coaly matter preventing the formation of sulphurous acid. The coating is then carefully removed and thrown away, unless it be of sufficient value to be used as a sulphur ore. The sulphates remaining in the heap are removed by long-continued exposure to the air, and occasionally watering. Another point to be attended to in such cases is to pile the blocks of ore with their planes of stratification upright, and not on their natural bed, as the pyrites contained in these ores is usually found interspersed in patches between these divisional planes, so that, by placing them on end, the escape of sulphur vapours is facilitated.

The second method of roasting between walls (*stadeln*) differs but little from that of open heaps or clamps—the heap being enclosed by vertical walls, forming three sides of a square or rectangular figure, and usually having an inclined floor. The height of the walls varies, with the nature of the ores, between 6 and 12 feet; two ranges of draught-holes, of 3 to 4 inches square, being pierced through them about 3 feet vertical distance apart, the lower series being close to the level of the ground. When the enclosed area is very large, it is necessary, in order to promote regularity of burning, to build up the large masses of ore so as to form a series of air-shafts in the interior of the heap, to which the air has access through a system of flues in the floor. This method of roasting is not in use in this country, but is practised in the Harz to some extent. The enclosing walls form in reality an imperfectly enclosed kiln, and there is some saving in the amount of fuel consumed, as compared with open piles. At Ilsenburg, in the Harz, clay ironstones are roasted in this manner, with a consumption of charcoal dust or braise to the extent of 6 or 8 per cent. of the weight of the ore.

Roasting in Furnaces or Kilns. This method is generally to be preferred, when economy of fuel is of importance, as the heat of combustion is more perfectly applied, and a more uniform product is obtained, than is the case with the ruder methods previously noticed.

The construction of the kilns used in different districts varies considerably, as will be seen by a few detailed examples following, but the principle of working is, in the main, the same everywhere—the ore being piled above a thin bed of fuel at the bottom of the kiln-shaft, which may be conical, cylindrical, barrel, or wedge-shaped in form, and when ignited is covered with layers of ore and fuel alternately until the shaft is full to the top or throat. The ore roasted by the combustion of the fuel at the bottom, where the air has access to the kiln, is withdrawn, and the next layer falls, the deficiency being made good by fresh charges at the top. In some instances, though not commonly, the heat is kept up by fuel burnt on side grates, so that only the flame has access to the interior of the kiln. Another plan, used to a considerable extent in Sweden, consists in the substitution of the waste gas of the blast furnace instead of solid fuel.

Kilns, when of a moderate size, are most conveniently made either of a conical, cylindrical, or any similar form presenting circular horizontal sections. For larger sizes, however, as it is found difficult to maintain a uniform temperature over circular areas of great diameter, the ore in the centre is liable to get too hot. It is preferable to build them of flattened elliptical sections, or rectangular with the corners rounded off.

At Dowlais, in South Wales, the kilns used are of a flattened elliptical plan (rectangular with semicircular ends), contracted from 9 feet in width at the top to 2 feet at the bottom. The length is 20 feet, and the height 18 feet. The floor is made of cast-iron plates 2 inches thick, and the interior is lined with fire-bricks, with an exterior casing of rough masonry. Two arched passages, slightly splayed outwards, are left in the lower part of the masonry, on one side extending back to the inner fire-brick lining, which is perforated, within the space covered by the arches, by four rectangular openings at the floor level for withdrawing the calcined ore, as well as by a numerous series of smaller holes above, which serve for the admission of air. The top edge of the kiln is covered by a flanged cast-iron ring, which protects the brickwork from abrasion by the lumps of stone in filling.

The method of working is as follows: two or three small coal fires having been lighted on the floor of the kiln, raw ironstone is placed on the top and around them until the whole is covered by a layer about 9 inches thick; when this has attained a dull red heat, a second layer is added, with about 5 per cent. by weight of small coal, and so on, fresh layers of stone being added as soon as the preceding charge has been heated to redness. When the kiln is completely filled, the lowest portion will be sufficiently cold and fit for drawing. The capacity of a kiln of the dimensions given above is about 70 tons, and will calcine 146 tons weekly, so that the average time of burning the charge is about three days and a half. The consumption of small coal is at the rate of 1 cwt. per ton of ore, whereas in calcining in piles or clamps 2 cwt. of small and ½ cwt. of large coal are required to do the same amount of work. The average loss of weight of Welsh argillaceous ores, when calcined, is 27 per cent.; of blackbands, from 40 to 60 per cent.; of red hematite, about 6 per cent.; and of Cornish, Devonshire, and similar brown hematites, from 12 to 14 per cent., although, under unfavourable circumstances, the latter have been known to lose as much as 26 per cent.

Gjers' calcining kiln, now largely employed in the

Cleveland district, is represented in transverse vertical section in Fig. 1. Unlike the massive kilns used in South Wales, the body or shell is of fire-brick only 15 inches in thickness, cased with wrought-iron plates in a similar manner to that now adopted usually in blast furnaces. The diameter at the top is 18 feet, at the boshes, or widest part, forming the junction of the two cones 20 feet, and at the bottom 14 feet. The horizontal section is everywhere circular. The bottom of the brickwork rests upon a flat cast-iron plate 4 inches thick, which is supported by a number of vertical cast-iron columns 27 inches high, leaving an open space all round between the bottom of the kiln and the floor. The latter is covered in with a cast-iron plate 20 feet in diameter and 2½ inches thick, cast in segments, carrying in the centre an upright cone of 8 feet in height and diameter. The total height from the foundation-plate to the filling gallery at the top is 24 feet, and the capacity 5,500 cubic feet. The ore remains in the kiln about two days and a half, the amount of fuel required being about 1 ton of coal slack for every 20 tons of ore. The admission of air from the exterior is regulated by a series of holes penetrating the brickwork near the bottom, and a further supply is introduced into the centre by means of a series of radiating flues in the brickwork of the foundation and the hollow in the overlapping part of the central cone. The roasted ore is drawn through the openings between the pillars,

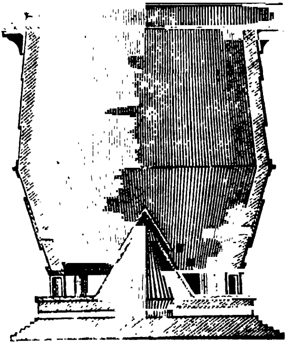
Fig. 1.—Gjers' calcining kiln.

being directed outwards by the slope of the interior cone. With larger kilns of similar construction, 34 feet high, the consumption of fuel is reduced to 1 ton per 25 tons of ore.

In the district of Siegen, the kilns used for roasting spathic ores are of cylindro-conical form, the conical part being placed with its smaller end downward below the cylinder. The average dimensions are: height 17½ feet, diameter at the top 5¾ feet, diameter at the bottom 3½ feet, and interior capacity about 500 cubic feet. The bottom of the conical part, which is about 3 feet above the level of the ground, is closed by a grate with bars 3 inches apart. A second grate about 2 feet below the first, and parallel to it, is used for starting the fire.

Before charging, a layer of pine charcoal 4 inches thick is placed upon the upper grate, which is succeeded by alternating layers of ore broken small, and fuel of an inferior quality, such as waste charcoal, breeze, coke or cinders from puddling furnace fires, or coke dust, in the proportion by measure of 40 cubic feet of ore to 8 of fuel, until the kiln is filled to the throat. A wood fire is then lighted on the lower grate, which soon ignites the charcoal on the upper one, and after a time, the coke and cinders mixed with the lower layers of ore. The fire on the lower grate is kept up for three days, the total consumption of wood being about 1½ cwt., when the ore at the bottom is found to be sufficiently roasted, and may be withdrawn. This is effected by removing the bars of the upper grate, and allowing the ore to fall out. About one-fourth of the whole contents of the kiln are drawn at a time; the bars are then replaced, and the kiln is filled with fresh charges, but the measure of fuel is reduced to one-half of that used at first. The next drawing takes place twenty-four hours later, and so on for several weeks in succession: one-quarter of the contents may be withdrawn daily. The average time of roasting the charge is, therefore, about four days.

The admission of air is regulated by draught-holes, with sliding registers placed above the upper grate.

The construction of a mine kiln using the waste gases of the blast furnace instead of solid fuel is shown in vertical section, Fig. 2, which represents one

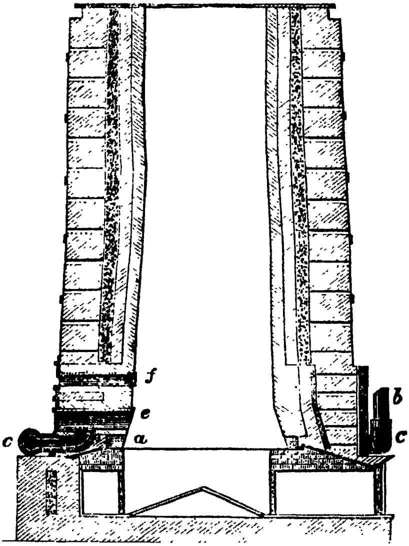

Fig. 2.—Swedish gas calcining kiln.

erected at Säfvenäs, in Lapland. It consists of a nearly cylindrical shaft $18\frac{1}{2}$ feet high, increasing in diameter from 5 feet at the top to 7 feet at the bottom, made up of three concentric casings, or walls of brickwork. The innermost wall or lining is formed of fire-brick, and is carried upon a cast-iron ring, *a;* the second and third are of common bricks, and divided by a layer of sand. The outer wall, about 2 feet in thickness, is perforated by numerous horizontal channels for the escape of moisture, and is further bound together by hoops of wrought iron. The plan of the base is cylindrical, perforated by five radial passages slightly splayed outwards, through which the roasted ore is withdrawn, the sides of these passages, as well as the bottom of the kiln, being protected by cast-iron linings. The gas coming from the blast furnace by the wrought-iron tube, *b*, passes into the cast-iron circular main, *c*, which is provided with ten jets placed at equal distances apart from the base. The necessary amount of air for combustion is admitted through the apertures, *e*, the supply being regulated by a sliding plate covering the mouth of the jet. Higher up is placed a second series of holes, *f*, through which bars may be introduced for breaking up lumps in the event of the charge clotting together from overheating. The ores are hard magnetite, and schistose or micaceous hematite mixed with quartz: they pass through, without undergoing any very great change, being mainly rendered friable, without alteration in the state of oxidisation of the iron; but iron pyrites, when present, is almost completely decomposed.

From 20 to 30 tons of ore are roasted daily, the only fuel employed being a portion of the waste gases of a small charcoal blast furnace.

At Söderfors a kiln has been recently built on the above principles, with the addition of a conical chimney with a damper, for more perfectly regulating the draught. In order to prevent fusion of the ore, air, at a pressure of $\frac{1}{4}$ to $\frac{1}{3}$ inch of water, is introduced through a hollow ring at the base of the shaft, provided with 24 small twyers, the supply being taken from the engine that blows the blast furnace. The dimensions are somewhat larger than those given in the preceding example, the shaft being 21 feet high, 9 feet in diameter at the base, and $5\frac{3}{4}$ feet at the throat; the chimney is 28 feet high. The daily production is from 35 to 50 tons.

In roasting spathic ores containing iron pyrites it is necessary to provide as much as possible for the free access of air in order to oxidise the sulphur which is partly volatilised as sulphurous acid, the remainder forming sulphate of protoxide of iron. Fig. 3 represents a simple form of pile or annular kiln, adopted at Mariazell, in Styria, for roasting this class of ore. It consists of a series of flat cast-iron rings 1 inch thick,

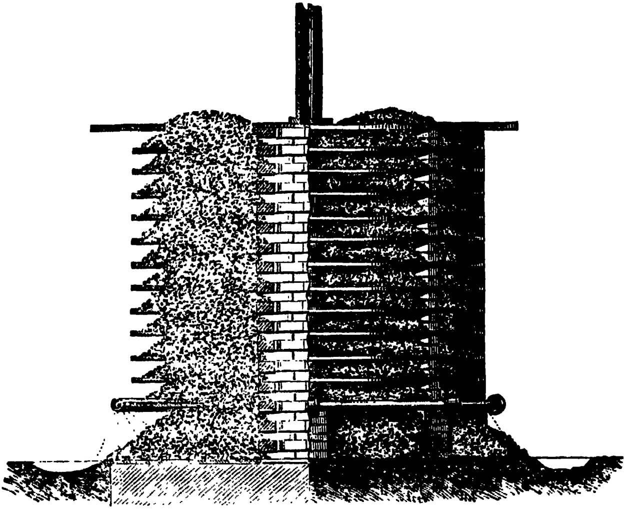

Fig. 3.—Styrian kiln for pyritic ores.

and 9 feet internal diameter, placed one above another. The bottom one is 2 feet wide, and is supported by eight piers of brickwork 12 inches square, and 20 inches high. The succeeding ones, eleven in number, are only 1 foot broad, and are kept at a uniform distance of 7 inches apart by piers similarly placed, formed of two bricks each. In the centre of the enclosed space is placed a cylindrical brick chimney 2 feet in diameter, having six holes of 3 inches square for regulating the draught in each course; these holes are made by leaving out alternate bricks in the manner usual in Staffordshire coke heaps. The top of the chimney is covered with a cast-iron plate, carrying a vertical cast-iron pipe for increasing the draught; at the bottom it is in communication with the external air by a rectangular flue 2 feet broad and 18 inches deep. A cast-iron water-pipe, provided with numerous small jets, surrounds the kiln at the level of the lower ring.

The charging is effected in the following manner: a bed of split wood, placed radially on the ground, is covered with a layer of charcoal dust amounting to four tubs of 7¾ cubic feet each. Upon this comes the first layer of ore, containing 45 barrows of 160 to 180 lbs. each, and so on in alternate layers in the same proportion, till the kiln is filled to the level of the top ring. The wood is lighted all round between the lower pillars. As soon as the fire has burnt through to the top, the drawing of the bottom layer may be proceeded with: this is usually done at intervals of from sixteen to twenty-four hours. About 6 tons of ore may be drawn daily; the loss of weight is about 20 per cent.

In order to remove the sulphates, the calcined ore is quenched with water from the main. The large lumps are broken, and it is then exposed to the action of the air in heaps about 2 feet high, which are repeatedly turned and watered, until all the soluble salts are washed out.

Experiments made with ores treated in this manner, after eight days' exposure to the air, proved that the sulphur had been sufficiently removed for the production of iron in the furnace. Formerly, from five to six years' exposure after roasting was required to obtain the same result, which necessitated keeping quantities of about 100,000 tons of ore under treatment, in order to supply the four furnaces in blast.

The desulphurisation of pyritic ores may also be effected by the action of steam at a red heat. This method was adopted in Finland, by Nordenskjold, in 1843, and has subsequently been used in Silesia and Westphalia. In the latter district it is applied to the roasting of blackband containing from 1 to 3 per cent. of sulphur. The kiln, which is somewhat similar in form to Fig. 2, is 25 feet high, 6 feet in diameter at the throat, with a conical shaft increasing to 9 feet at 19 feet below the mouth: the remaining height of 6 feet is cylindrical. Near the bottom is introduced a wrought-iron pipe 2 inches in diameter, and terminating in a conical jet or rose, perforated with numerous small holes. The charging takes place in the usual way, upon a bed of kindling wood: no coal is used, as the ore is sufficiently carbonaceous not only to calcine itself, but also a further quantity of magnetic ore smelted at the same place. As soon as the contents of the kiln are red hot, superheated steam at 36 lbs. pressure is admitted through the conical jet-pipe for a few minutes at a time, at intervals of half an hour, which, acting on the pyrites, gives rise to sulphuretted hydrogen and peroxide of iron. In order that the sulphides may not be re-formed in the upper part of the shaft, it is necessary to admit air freely, so that the sulphuretted hydrogen may be resolved into water and sulphurous acid. By this means the whole of the sulphur is almost entirely removed. In a kiln of this kind, 12½ tons of magnetic ore and 3¾ tons of blackband are calcined daily.

CHAPTER VII.

OF THE FLUXES USED IN IRON-SMELTING.

THE general principles upon which the employment of fluxes is based have already been alluded to in describing the method of assaying by the dry way. In practice very few ores are found to contain earthy ingredients in proportions sufficient to form readily fusible slags alone, and it therefore becomes necessary to supply the deficiency. This may be done either by mixing ores of dissimilar composition, as, for instance, siliceous with calcareous hematites, or both with argillaceous ores in such quantities as shall yield slags of the desired composition, or by the addition of calcareous or aluminous minerals not containing iron. The first of the above methods is undoubtedly to be preferred to the other, as by it we are enabled to form the slag without unnecessarily reducing the percentage of iron in the charge or burden taken as a whole, whereas the addition of fluxes increases the weight of material to be passed through the furnaces for the same produce of metal, but it can only be carried out in districts having a large and varied command of minerals. As a rule, therefore, a combination of both methods is used, the best mixture of ores obtainable being supplemented by the addition of earthy minerals.

The principal flux employed by the iron smelter is carbonate of lime, in the form of limestone, which is usually obtained from a neighbouring quarry. The best varieties are those containing the largest amount of carbonate of lime, but alumina and iron may be present advantageously. In the latter case limestones often pass insensibly into calcareous hematite or magnetite, which form excellent mixtures with more siliceous ores of the same class. Very fossiliferous limestones often contain notable amounts of phosphoric acid and iron pyrites, and are to be avoided. Dolomitic or magnesian limestones are less generally useful than more purely calcareous varieties, as the fusibility of slags is diminished by the addition of magnesia beyond very moderate quantities.

Rich iron ores occurring in crystalline rocks, such as those of Sweden, Norway, and North America, are often accompanied by limestones containing silicates of lime and magnesia of a low degree of silication, such as pyroxene, hornblende, garnet, idocrase, chlorite, all which may be regarded as ready-formed slags. The use of these substances as fluxes is usually attended with a great economy of fuel. Such ores are known in Sweden as *self-gaejende, i.e.* self-going or self-fluxing. A somewhat similar effect may be obtained by the use of blast-furnace slag a second time, if it be sufficiently basic to carry an extra dose of silica; but this is rarely done except under pressure of adverse circumstances. Percy relates a case of this kind as having occurred in South Wales, where slags were used a second time without injuring the quality of the iron produced, when the supply of limestone was temporarily cut off.

The following table shows the average composition of some of the commoner varieties of limestone used by iron masters in England and Wales :—

Analyses of Limestones used in English Iron Works.

	I.	II.	III.	IV.	V.
Carbonate of lime . .	97·31	95·26	97·54	89·36	96·15
Carbonate of magnesia .	1·00	2·21	0·90	0·97	1·32
Carbonate of protoxide of iron	0·62	—	—	3·38	—
Alumina and peroxide of iron . . . . Silica	1·27	2·98	1·35	6·00	3·20
Organic matter . .	0·20	—	—	—	—
Water	—	—	—	0·43	—
	100·40	100·45	99·79	100·14	100·67

No. I. Silurian limestone, Dudley. Used in South Staffordshire.
„ II. Carboniferous limestone, Harmby, Durham. Used in Cleveland.
„ III. Permian limestone, Raisby Hill, Durham. Used in Cleveland.
„ IV. Oolitic limestone, Wellingborough. Used in Northamptonshire.
„ V. Chalk, after deducting 21 per cent. of water. Used in Cleveland.

In the Lancashire and Cumberland hematite district, where the rich red ores of Ulverstone and Whitehaven are smelted alone, argillaceous fluxes are necessary in addition to limestone. For this purpose the shale of the coal measures is generally added; but latterly a peculiar variety of brown hematite, remarkable for containing a large quantity of free alumina, has come into use in these districts, and also in South Wales. This substance is known as "Belfast Aluminous Ore." A somewhat similar mineral, called Bauxite, found at Baux, in the south of France, is now used to a considerable extent as an ore of aluminium.

Analyses of Aluminous Ores and Fluxes.

	I.	II.	III.	IV.
Silica	61·91	9·75	9·87	2·8
Alumina	21·73	27·95	34·57	57·4
Peroxide of iron	—	35·91	27·93	25·5
Protoxide of iron	4·73	6·57	5·08	—
Lime	0·09	0·60	0·91	0·2
Magnesia	0·59	0·20	0·62	—
Potash	3·16	0·49	—	—
Soda	0·25	—	—	—
Titanic acid	—	—	3·51	3·1
Volatile	7·43	18·60	19·36	11·0
	99·89	100·12	101·85	100·0

No. I. Coal measure shale from the neighbourhood of Manchester. Frankland.
„ II. Belfast aluminous ore. Tookey.
„ III. Another sample of the same ore.
„ IV. Bauxite, from Baux, in the south of France. Bell.

Caustic lime is sometimes used instead of limestone, and produces a certain economy of fuel, as the local cooling, owing to the absorption of heat in the blast furnace consequent on the expulsion of the carbonic acid, is done away with. Comparative experiments on this point have been made at Ougrée, in Belgium, and Konigshütte, in Silesia. In the former case, 26 per cent. of lime replaced 40 of limestone, and the production of metal was increased 2·3 per cent., with a saving of 1·6 per cent. of coke. In the latter the saving was 2·85 per cent., and the increase of production 3·1 per cent. It is of course necessary to use the lime as soon as possible after burning, in order to prevent it taking up moisture from the air.

Forge and Mill Cinders. It will be convenient to notice these substances, which play a very important part in the economy of modern iron works, before leaving the subject of iron ores, although, strictly speaking, they cannot be classified with them, but are rather to be considered as waste products, which are produced and regularly economised on a very large scale. When melted pig iron is exposed to the oxidising action of the air, its combined silicon is oxidised, with the formation of tribasic silicate of protoxide of iron, which is very fusible, and is capable of taking up a further amount of iron, probably in the form of magnetic oxide. The same thing takes place when wrought iron is heated in contact with silica, at a welding temperature. It will subsequently be shown that the slags or cinders produced in the various operations of refining, puddling, and reheating, performed in the conversion of cast into malleable iron, are of this composition. The amount of iron contained varies from 40 to 75 per cent., and in this respect cinders might be considered as equal to the richest iron ores, were it not that practically the whole amount of phosphorus contained in the pig iron operated upon is also taken up, as well as more or less sulphur, so that in reality their use in the blast furnace tends to deteriorate the quality of the metal produced, when entering into the charge beyond a certain proportion.

The chief reason, however, for the deterioration is to be found in the ready fusibility and comparatively difficult reducibility of the cinders, which, when added to the charge in the blast furnace, are apt to melt and run down into the hotter part of the furnace above the hearth, where the reduction of iron and silicon takes place simultaneously. Only a portion of the silicate, however, is so reduced: the remainder, passing into the blast-furnace slag, produces the so-called black or scouring cinder, which not only acts injuriously upon the siliceous matters of the hearth, but prevents the formation of cast iron at a maximum of carbonisation. The result is therefore an inferior description of white iron, usually known as cinder pig, together with the loss of a considerable quantity of iron in the slag, which sometimes contains nearly 20 per cent. of protoxide of iron.

The purest class of cinders are those from the reheating or welding furnace, being freer from sulphur and phosphorus than those obtained in puddling. Various methods have been suggested for overcoming the difficulties attendant on the smelting of cinders, such as subjecting them to a preliminary calcination, or combining them with lime and small coal in order to effect the reduction at a lower temperature. Of these methods only the former has been generally adopted. When silicate of protoxide of iron is roasted, either in heaps or kilns, with a free access of air it is decomposed, with a separation of silica: the protoxide of iron, absorbing oxygen, passes into the state of peroxide, or magnetic oxide, producing a very refractory substance, which is employed, under the name of "bulldog," for lining the hearths of puddling furnaces. Its infusibility is due to the fact that silica and peroxide of iron are both infusible, and do not combine together when exposed to a high temperature in an oxidising atmosphere. When the bulldog is produced from puddling-furnace cinders containing phosphorus in quantity a partial liquation takes place, and a fusible slag, known as *bulldog slag*, separates, carrying down with it a considerable portion of the phosphorus. Sulphur, when present, is almost entirely removed during the roasting, being converted into sulphate of iron, which forms a crust over the outer surface of the heap, and may be washed out with water, or decomposed by further heating. It will readily be seen that when the iron is peroxidised it is in a much more favourable condition for treatment in the blast furnace, and the cinders may then be regarded as equivalent to a siliceous hematite.

In Lang's method of preparing puddling and other forge cinders for the smelting furnace they are finely powdered, and mixed with milk of lime and coal slack, or charcoal dust, into a paste, which, when dry, forms a hard mass, and may be broken into lumps, having sufficient coherence to stand the pressure of the blast furnace without crushing. At Storé, in Carniola, where this process was introduced in 1861, sixty-six parts of reheating furnace cinder, mixed with 22 parts of lime and 12 parts of charcoal dust, were smelted in a cupola without any addition of ore, and produced mottled pig iron of good quality. Several analyses of pig iron so produced have been published, but the composition of the cinder operated upon is not given.

A somewhat similar process has been proposed by Minary and Soudry. The cinder, in a finely-divided state, is mixed with caking coal slack, and converted into coke in the ordinary way. According to the statements of the inventors, the protoxide of iron in the cinder is said to be reduced to the metallic state by the gases given off during the coking, at a temperature sufficiently low to be without effect upon the silica; at the same time both phosphorus and sulphur are eliminated as phosphuretted and sulphuretted hydrogen. The coke produced is intended to be used in the blast furnace for smelting ores. In order to obtain it sufficiently coherent, it is necessary to keep the mixture of slack and cinders with certain proportions. The best results were obtained at Givors, with 40 of the latter to 60 of the former, which gave a coke containing from 20 to 25 per cent. of metallic iron ; but the proportions might be reversed without consuming any of the fixed carbon of the fuel in the reduction, which is effected entirely by the volatile products. The removal of the uncombined silica must, of course, be provided for by the addition of a proportionate quantity of limestone. over and above that required by the ore in the blast furnace.

The above statements are, to a certain extent, in opposition to the results obtained by Percy and Richardson, who found that the tribasic silicate of protoxide of iron could not be entirely reduced to the metallic state when heated with an excess of carbon, two atoms only of the protoxide being separated, leaving behind a monobasic silicate ($FeO. SiO^3.$), which resisted further change. This result can only be obtained with chemically pure tribasic silicate, such as is prepared by fusing pure peroxide of iron with quartz sand, whereas the cinders produced in puddling or heating furnaces, always contain a sufficient proportion of earthy bases to allow the last atom of iron to be set free.

The addition of fluxes in the blast furnace is regulated by several considerations. When the ores are of good quality, the chief point to be considered, is the production of the most fusible slag with the smallest addition of non-ferriferous matters ; this is more especially the case with charcoal furnaces. When mineral fuel is used, however, it is necessary to form a slag that is capable of absorbing sulphur, which would otherwise be taken up by the iron, and for this purpose, a larger quantity of flux is used than that indicated by theory as giving the most fusible product.

The fusibility of silicates depends chiefly upon their composition, and, according to Plattner, increases with the increase of silica: thus for the same base the monobasic ($RO.\ SiO^3$) and sesquibasic ($3\ RO.\ 2\ SiO^3$) forms are more fusible than the tribasic, containing $3\ RO.\ SiO^3$, or the subsilicate, $6\ RO.\ SiO^3$. For the same composition, silicates containing one base are less fusible than those containing two or more. The following is the observed order of fusibility in the simple silicates :—

Silicate of Alumina	melts at	2,400° C.
,, Magnesia	,,	2,200° — 2,250°
,, Baryta	,,	2,100° — 2,200°
,, Lime	,,	2,100° — 2,150°
,, Protoxide of Iron ,, ,, Manganese	,,	1,789° — 1,832°

Of double silicates of similar atomic composition, those containing both protoxide and sesquioxide bases are more fusible than those having both bases of the protoxide type, the order of fusibility being as follows :—

Silicate of Baryta and Lime	melts at	2,100° C.
,, ,, ,, Alumina	,,	2,050°
,, Lime ,, Magnesia	,,	2,000°
,, ,, ,, Alumina	,,	1,918° — 1,950°

The most fusible of the triple silicates likely to be produced in iron-smelting are those containing alumina, lime, and protoxide of iron, or manganese. Silicates of potash and soda, or of protoxide of lead, are among the most fusible; but with these we are not at present concerned.

The slags of blast furnaces may be regarded as silicates, whose composition ranges between the following limits :—

I. $3\ CaO.\ 2\ SiO^3 + Al^2O^3.\ 2\ SiO^3$; and
II. $3\ CaO.\ SiO^3 + Al^2O^3.\ SiO^3$.

Those of charcoal furnaces are mixtures in indefinite proportions of both silicates, while those produced with coke or coal are more basic, and approach more nearly in composition to No. II.

In the first of the above formulæ the oxygen of the silica is double that of the bases taken together, corresponding to the composition $3\,RO.\ 2\,SiO^3$, or that of augite; while in the second both bases and silica contain equal amounts of oxygen, giving the formula $3\,RO.\ SiO^3$, or that of olivine.

As a portion of the lime may be, and usually is, replaced by other protoxide bases, and also alumina may be partially substituted for silica, it is evident that these general expressions may be made to include substances differing widely in qualitative composition. The following are the maximum and minimum limits of the chief constituents of blast-furnace slags derived from the examination of a large number of analyses:—

	Min.	Max.	
Silica	20	72	per cent.
Alumina	0	30	,,
Lime	0	60	,,
Protoxide of iron	0	26	,,
,, manganese	0	34	,,
Magnesia	0	34	,,
Baryta	0	8·2	,,
Soda	0	11·3	,,
Potash	0	4·3	,,

Bodemann gives the following formula for the most fusible silicate of lime and alumina:—

$4\,(3\,CaO.\ 2\,SiO^3) + 3\,(Al^2O^3.\ 2\,SiO^3)$, containing, per cent., Silica, 56; Lime, 30; Alumina, 14.

The following are a few examples of slags produced under different conditions of working. The composition of the slags from furnaces in different localities, and under dissimilar conditions of working, is illustrated in the following table, as far as it can be done with such a small number of examples :—

ANALYSES OF BLAST FURNACE SLAGS.

	I.	II.	III.	IV.	V.	VI.	VII.
Silica . .	38·48	43·07	31·46	27·68	42·96	61·06	40·95
Alumina . .	15·13	14·85	8·50	22·28	20·20	5·38	8·70
Lime . .	32·82	28·92	52·00	40·12	10·19	19·81	30·36
Protoxide of iron . .	0·76	2·53	0·79	0·80	19·80	3·29	0·60
Protoxide of manganese .	1·62	1·37	2·38	0·20	1·53	2·63	2·18
Magnesia . .	7·44	5·87	1·38	7·27	2·90	7·12	16·32
Sulphide of calcium . .	2·22	1·90	2·96	2·00	1·32	—	Sulphur. 0·34
Alkalies . .	1·92	1·84	—	—	1·10	—	0·32
Phosphoric acid	0·15	—	—	—	—	—	0·10
	100·54	100·35	99·47	100·35	100·00	99·29	99·87

No. I. From Dowlais, produced when making grey iron. Riley.
„ II. „ „ produced with white iron. Riley.
„ III. „ Kirkless Hall, Wigan, produced with grey Bessemer iron, disintegrates in the air.
„ IV. „ Clarence, Durham, from Cleveland ores. Bell.
„ V. „ Cwn Celyn, South Wales, scouring cinder. Noad.
„ VI. „ Gosberg, Sweden. Sjogren.
„ VII. „ Neuberg, Styria, produced with grey iron. Küppelwieser.

It occasionally, but rarely, happens in the smelting of spathic ores, that slags are produced entirely free from lime. The following are examples of this kind :—

	I.	II.	III.
Silica	49·57	48·39	37·80
Alumina	9·00	6·66	2·10
Protoxide of iron	0·04	0·06	21·50
Protoxide of manganese . . .	25·84	33·96	29·20
Magnesia	15·15	10·22	8·60
Sulphur	0·08	0·08	0·02

No. I. From Siegen, produced with grey iron. Karsten.
„ II. „ „ „ „ spiegeleisen. Karsten.
„ III. „ Styria, „ „ white iron. Von Mayrhofer.

When the fusibility of a slag is reduced, by the addition of lime in excess, the iron will be highly carburetted, and the greater amount of sulphur will be taken up by the slag in the form of sulphide of calcium. Other things being equal, the iron will be grey if the slag is refractory, and white if it is very fusible. The reason of this is apparent when we consider that the iron may be reduced and carburetted, but cannot separate from the earthy matters till these have melted into slag; if, therefore, the latter are very fusible, the metal which melts at a still lower temperature runs together, or falls through the region of the boshes and hearth, where the temperature is highest, without being exposed for any length of time to the energetic reducing agencies prevailing at and near the interior. If, on the other hand, the finely-divided particles of metal are kept from coalescing by the more refractory character of the slag, it will be subjected to a long-continued heating in a region favourable to the accumulation of carbon and silicon in the highest degree, and it is to the presence of the latter element that the greyness of pig iron is in part, at least, due.

The power of taking up sulphur is also imparted to slags by protoxide of manganese, as well as lime,—a property that receives an important application in the manufacture of spiegeleisen from manganesiferous spathic ores.

Protoxide of iron increases the fusibility of slags, communicating at the same time a dark green or black colour, as is seen in the so-called scouring in black cinders which are produced when a furnace is working with a heavy burden, or increased charges of ore and fluxes in proportion to the fuel.

These slags are accompanied by the production of white iron, from the reduction of a portion of the protoxide of iron in the molten silicate when brought into contact with the bath of cast iron in the hearth, at the expense of the carbon in the molten metal. With silicate of protoxide of manganese, however, this reaction does not take place, owing to the very high temperature required for the reduction of protoxide of manganese to the metallic state.

The physical character of slags, such as colour, texture, fluidity, &c., varies with their composition and the working condition of the furnace, so that it is not possible from inspection alone to determine the character of the metal produced, except after considerable experience of the individual furnace; and the relation between slag and metal in one district may be totally different in another. De Vathaire makes the following general observations on this point, which, of course, must be taken as applicable only within wide limits:—

Slags produced from furnaces working hot—*i.e.* with light burden—when the reducing power is at a maximum, and grey iron is made, are usually white or grey. Owing to the total amount of iron being reduced, in the special case of the ores containing manganese, an amethystine tint is often observed under these conditions, especially in charcoal furnaces smelting hematite or non-aluminous ores.

Black slags, on the other hand, correspond to heavy burden, and a comparatively reduced temperature, when the furnace is said to be working cold, or with less fuel as compared with the weight of the charge smelted.

The vitreous character and fluidity of slags increase in proportion to the amount of silica. A porcelanic or opalescent character is generally indicative of a considerable amount of alumina. Those produced in the smelting of coal-measure clay ironstones are often of this character, showing an alternation of light yellowish and dark green or blue bands and stripes. Slow cooling has a tendency to produce devitrification or crystallisation, so that it often happens that the same slag forms a perfect glass when suddenly solidified, but becomes opaque or porphyritic, with distinct crystals interspersed through a vitreous base, when cooled very gradually.

When slags containing sulphides of calcium, barium, and manganese, such as are commonly produced when sulphur is present in the fuel, are allowed to flow over damp ground, in smelting with coke, steam is forced through the molten mass, which, in its passage, is decomposed by the sulphides and poly-sulphides, with the production of sulphuretted hydrogen. This in its turn burns on coming in contact with the air, giving rise to sulphurous acid gas. If, however, water be thrown upon the surface of the slag, the sulphuretted hydrogen evolved is prevented from igniting, escapes unaltered, and may be recognised by its unpleasant odour. The reactions are as follows, according to whether a neutral or poly-sulphide of calcium be present:—

$$\mathrm{CaS} + \mathrm{HO} = \mathrm{CaO} + \mathrm{HS}.$$
$$\mathrm{CaS^5} + 3\,\mathrm{HO} = \mathrm{CaO} + \mathrm{SO^2} + \mathrm{S}\ 3\,\mathrm{HS} + \mathrm{S}.$$

In the latter case the decomposition is more complex, being attended with the formation of sulphurous acid, sulphuretted hydrogen, and free sulphur. Under ordinary conditions, however, the two latter products would unite and burn to sulphurous acid. This is probably the cause of the strong odour of this gas usually produced by the slags escaping from a coke furnace working very hot.

When lime is present in large quantity, the fracture of the slag is usually of a dull stony character. Those of the Cleveland and Lancashire hematite furnaces are of this kind. A very large excess of this base causes the slag to fall to pieces when exposed to a moist atmosphere after cooling, in the same way as caustic lime, forming a powder which may be employed in making cement or mortar for building purposes.

In many of the small iron works of Germany the slags are subjected to the processes of stamping and washing, in order to recover any entangled shots of metal, which are afterwards returned to the furnace.

As a general rule, steady and continuous flowing, a somewhat viscid fluidity, and a slow passage from the liquid to the solid state, are characteristic of the slags produced from furnaces working hot. Scouring slags, on the other hand, run as liquid as water, but solidify in crusts rapidly, without passing through the plastic state.

Slags produced from manganesiferous hematites are of the usual manganese, violet, or amethystic tint in the vitreous portions, but when blown up by gases, the colour disappears, with the production of a pearly-white pumice-like body. When the same furnaces are burdened for white iron the slags become dark green, and of an almost pasty consistency.

In addition to the colours produced by metallic oxides, such as bottle-green or black by protoxide of iron, violet by protoxide of manganese, yellow or brownish green by protosulphide of manganese, others, especially shades of blue, are common in slags;

but it is not clearly made out what the colouring agent is in such cases. Thus a bright sky-blue tint, often seen in Swedish slags, has been variously attributed to vanadium, titanium, and sulphide of sodium (ultramarine). Silicate of zinc is also stated to produce green and blue tints.

CHAPTER VIII.

OF THE BLAST FURNACE AND ITS ACCESSORIES.

It has already been stated that in the early days of iron-smelting the only merchantable product was bar or malleable iron obtained directly from the ore; cast iron being a subsequent discovery, consequent upon the employment of larger furnaces and higher temperatures in the treatment of more refractory minerals. In process of time, it was found that the production of cast or pig metal, as an intermediate stage in the manufacture of malleable iron, was attended with advantages not possessed by the older method, so that at present it is followed exclusively; the latter being confined almost entirely to a small and constantly diminishing area in Europe, besides being more extensively practised in Africa and India.

The subject, therefore, naturally divides itself into two main heads:—

I. Direct method, or extraction of malleable iron from the ore, and

II. Indirect method, or production of pig iron from the ore, and subsequent conversion into malleable iron by some form of finery process.

The difference between the two processes is mainly due to the height of the furnace. In the direct method, where a low charcoal hearth or forge is used, a portion of the ore is reduced to the metallic state at a comparatively low temperature, while another part combines as protoxide with any silica that may be present, forming a highly fusible and basic slag, into which the reduced spongy mass sinks, any excess of carbon taken up being removed by the oxidising agency of the slag, aided by the blast which is introduced through an inclined nozzle or twyer, so as to impinge directly upon the metallic bath.

On the other hand, the furnace used for the production of cast iron is mainly distinguished by its height, and may be described in general terms as a conical hearth, whose walls are continued upwards into a chimney or stack of increasing but variable section; the blast-nozzle being laid horizontally instead of in an inclined position. The height of the upper portion, *i.e.* above the twyer level, may be from ten to twenty times as great as that below, or hearth proper. When the furnace is at work, or, as it is technically termed, *in blast*, it is kept filled to the top or *throat* with alternate layers of fuel, ore, and flux, the latter being mixed in proper proportions to produce the most fusible combinations of the earthy matters, a constant stream of air being maintained through the twyers, at a sufficient pressure to pass freely through the contents of the furnace. Part of the incandescent fuel subjected to the blast is completely consumed, burning to carbonic acid with a development of the maximum of heat, whereby the matters immediately adjacent are melted, and fall into the hearth, where they separate by liquation into metal and slag; the latter, being specifically lighter, rises to the surface, and protects the former from the decarburising action of the blast. The carbonic acid formed in the first instance, encountering fresh fuel, is reduced to the state of carbonic oxide, a process that is attended with a great absorption of heat, so that the region in which a temperature sufficiently high for the fusion of metal and slag prevails does not extend more than a very short distance from the point of introduction of the air. The carbonic oxide so produced, and the unaltered nitrogen of the air, when brought in contact with an oxide of iron at a red heat, is again oxidised to carbonic acid, with the simultaneous production of metallic iron, which becomes carburetted by further contact with carbonaceous matters in its descent towards the hearth.

The alternate production of carbonic acid and carbonic oxide, by the reciprocal action of carbon and oxides of iron upon the gases, is continued in the upper part of the furnace as long as the temperature remains sufficiently high, the quantity of the former gas being augmented by the decomposition of the limestone flux generally used. Ultimately, however, a sufficient amount of carbonic oxide remains in the so-called waste gases, either to form a great body of flame at the throat of the furnace when the current is allowed to flow freely into the air, or a valuable fuel, yielding sufficient heat for all the accessory operations of the furnace, when collected and utilised.

The shaft of the blast furnace may, therefore, be considered as combining within itself, and performing the functions of, several distinct furnaces; thus the hearth is devoted entirely to fusion, while the middle region is essentially a concentration chamber, and the top parts, when raw fuel and flux are used, combine the functions of a limekiln with those of a coke oven.

Taken as a whole, therefore, the reactions in the manufacture of pig iron are more complex than those of the open-fire process of making malleable iron direct from the ore; but, as the latter is only one out of many methods by which the same product is obtained, it will be more convenient to defer its consideration, and commence with a description of the former.

Of Blast Furnaces. In its original, or what may be considered typical form, the blast furnace consists of a shaft or chamber formed of two truncated cones, joined by their bases. The upper and more acute of the two cones is placed upright, and is known as the *stack*, while the lower and more obtuse one is inverted: the line of junction forming the widest part of the furnace is called the boshes, possibly a corruption of the German *bauch*. Sometimes the lower cone is continued down to the level of the ground, but more generally the lower part of the furnace is enlarged, forming what is known as the *hearth*, in which the molten materials collect below the level of the twyers or pipes through which the blast is introduced.

In France, the space between the twyers and the broadest part, or top, of the boshes is known as the laboratory or working place (*ouvrage*).

The top, or throat, of the furnace is surrounded by a platform for the convenience of charging, and is in many cases covered by a short cylindrical chimney, which leads off the flame escaping at the throat; this portion of the furnace is known as the *tunnel head*.

In the newer forms of furnaces, the conical or spindle-shaped body and cylindrical hearth, with their sharply-contrasted divisions, are, for the most part, superseded by more flowing forms, the straight slopes of the sides being converted into curves, giving a more or less barrel-shaped outline to the stack. The same terms are, however, alike applied to the different parts, the boshes being taken as indicating the widest part of the stack, and the hearth that lying below the twyers.

It will be beyond the province of an elementary sketch like the present to enter into elaborate details of the construction of blast furnaces; only some of the leading points will be noticed in the following order:—

I. External form and construction.

II. Details of the interior lining, or working parts.

III. Construction of the hearth and furnace top.

IV. Accessory apparatus, such as lifts, blast engines, and stoves.

V. Methods of collecting waste gases.

The construction of blast furnaces varies very considerably in different localities, in regard to size and proportion of parts to each other, as well as material employed. In the early days of pig-iron manufacture, when a square horizontal section was in general use, the external form was usually that of a square base, pyramidal tower, tapering uniformly from the ground upwards, which became modified, on the introduction of the circular stacks, to a conical or cylindrical form, the lower portions near the ground, and surrounding the hearth, still retaining the square base. Both of the above forms are characterised by extremely massive construction, the lower parts, or stack pillars, forming solid four-sided blocks of masonry, braced with iron rods, and united by cylindrical arches into the so-called twyer houses, a complete circular passage being usually formed through the mass of the pillars. When the whole furnace is of rectangular section it is braced by a similar system of tie rods through the entire height, but in conical or cylindrical forms iron hoops, placed at short distances apart, are used for the same purpose. With every increase of size the massive character of the external casing of the blast furnace has diminished by the reduction of the mass of masonry, and the substitution of cast and wrought iron whenever it is possible to do so. Thus in many modern English furnaces the old stack pillars and twyer houses have been replaced by cast-iron columns or standards, arranged in a circle, whose entablature is a cast-iron ring, carrying the whole of the superstructure, or stack, so that the hearth casing, instead of being accessible

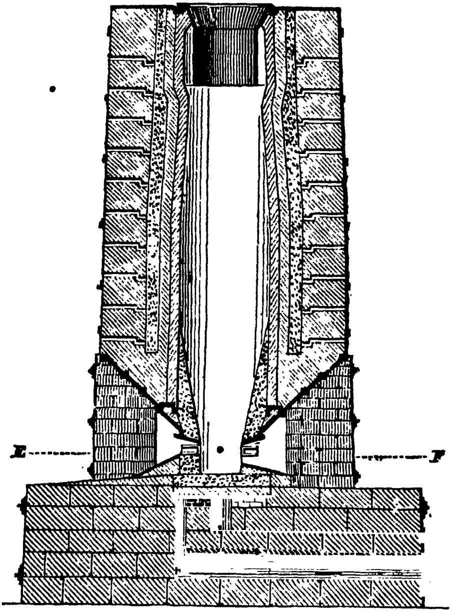

Fig. 4.—Swedish charcoal blast furnace, vertical section on line A B, Fig. 5.

Examples of these different forms of construction may be seen in almost every iron-making district. The

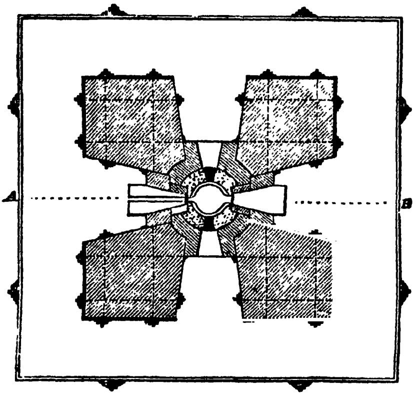

Fig. 5.—Swedish charcoal blast furnace plan at E F, Fig. 4.

older kinds, with massive stacks, are, as might be expected, to be found chiefly in the older districts, such as South Wales, Staffordshire, and Scotland; while in the newer furnaces of the north-eastern counties and Lancashire, the iron-jacketed cupola type is more commonly seen.

Figs. 4 and 5, which are the section and plan of a small charcoal blast furnace at Säfvenäs, in Lapland, may be taken as an example of the more massive construction, with square pillars and a round stack, while

Fig. 6 represents the cupola form of furnace, being the section of a large coke furnace, smelting hematite, at Barrow-in-Furness, Lancashire. The other points in the construction of both these furnaces will be referred to in the sequel. They are placed here merely as types of construction.

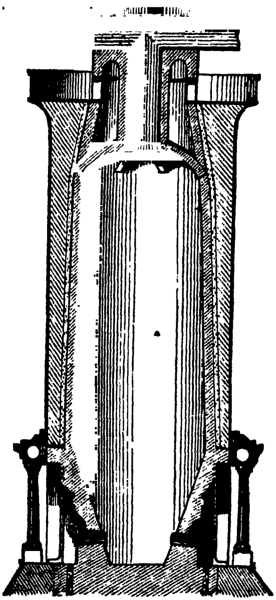

Fig. 6.—Cupola blast furnace, Barrow-in-Furness.

In some of the furnaces of Sweden and Finland, which are of comparatively small dimensions, the outer casing is formed by a crib-work of wood, like a log hut, the intermediate space between it and the interior furnace stack being filled in with earth.

Construction of the working Parts of the Furnace. The shaft, or stack, of the furnace, *i.e.* the upper part above the boshes, is constructed at the same time as the casing. It is now invariably formed of fire-bricks, which are moulded to the proper curve of each ring. The thickness of the shaft or ring wall is about 15 or 18 inches, the joints being brought to a fine face and set in fire-clay. A second wall is, in the more massive class of furnaces, placed immediately outside the first; this may be either of common or seconds fire-brick, and set in cement; outside of all, comes the exterior casing, which, as has been already stated, may be either of iron, brick, or masonry.

A small annular space, filled either with loose sand or small fragments of broken slag, is usually interposed between each successive lining, in order to allow for any alterations of form produced by the expansion of the inner one. In the outer casing a number of square holes are often provided for the escape of moisture; these are more especially used in furnaces which only remain in blast for a certain period of the year, as is the case in Sweden, but in those that work continuously, they are often omitted.

The lower portion of the furnace, including the hearth and boshes, is built after the completion of the stack. The foundation of the hearth varies with the nature of the ground, and may sometimes require to be commenced, in concrete and rubble work, at a considerable depth below the surface; the hearth bottom consists of a thick layer of fire-brick, or sandstone, in blocks of as large a size as can be obtained, or in some cases both materials are used. The bricks for this purpose are laid in the form of an inverted flat arch, in order that they may not be forced up in the event of the molten metal finding its way through the joints. When a bed of masonry is used below the hearth bottom, it is generally built with a system of channels or flues intersecting at right angles, through which air circulates, and prevents the access of moisture from the ground to the hearth. The arrangement of these flues is shown in Fig. 4.

The sides of the hearth and boshes, up to their junction with the stack, require to be made of refractory material, and also of considerable thickness, having to withstand a very high degree of heat, in addition to the common action of the molten slags. When the rectangular hearth was used, it was customary to build these parts of sandstone similar to that employed for the hearth bottom, but for the circular form brick is generally adopted, and is in almost all cases to be preferred.

In Sweden and Germany the hearth and boshes are often formed of a mixture of finely-crushed quartz or ground fire-brick, and fire-clay, applied in a plastic state, and rammed tight between the casing walls and a wooden core or mould of the proper shape of the cavity required, which is afterwards removed. This kind of hearth, which is represented in the Swedish furnace, Figs. 4, 5, is found to answer well in practice for furnaces of small diameter, but requires to be very carefully dried before being heated, in order to prevent irregular shrinkage and cracking.

A short distance above the ground level the passages for the introduction of the blast are perforated through the wall of the hearth. These are known as the *twyer holes,* and vary in number from two to six. On the front or working side of the hearth, a square or flat-arched opening extends from the hearth bottom to a little above the level of the twyer holes. The vertical sides of this opening are prolonged outwards for a short distance into a rectangular cavity, known as the fore-hearth, which is bounded in front by a wall of refractory material, called the *dam.* The arch covering the opening is called the *tymp arch.*

The exterior of the hearth, and the faces of the numerous apertures pierced through it, are strengthened with cast-iron plates and wrought-iron bracings. The under side of the arch is, in large furnaces, usually protected by a cast-iron box or block, having a wrought-iron serpentine pipe inside, through which a current of water is kept flowing, in order to protect the brickwork from destruction by the intense heat to which it is exposed, and the corrosive action of the molten slag which is constantly flowing through it.

The dam in front of the hearth is formed of firebrick, and is carried up to the twyer level. Externally it is supported by a cast-iron plate, called the dam plate. A semicircular furrow in the top edge, known as the cinder notch, forms a passage for the slag, which is now often moulded into large blocks by receiving it in a shallow square-bodied railway truck, having movable sides of wrought iron. When the truck or *cinder tub* is full, it is removed, and the block of slag, weighing in some instances as much as 7 tons, is, as soon as it has cooled sufficiently to become solidified, removed and thrown away. In charcoal and other small furnaces, the front of the dam is generally formed into a gently-sloping inclined plane or *cinder fall,* where the slag as it runs out solidifies in a comparatively thin layer, and may be broken up and removed by hand. In Staffordshire, the slag is allowed to collect in a shallow basin in the floor of the casting house, called the roughing hole, where it consolidates to an irregular disc-shaped lump, which is afterwards lifted out by a crane, and sent off on a truck to the slag bank or cinder tip.

The tap-hole for withdrawing the molten iron from the hearth is a narrow vertical slit pierced through the dam, and extending from the hearth bottom about 12 or 15 inches upwards. During the time that the hearth is filling, it is stopped by a packing of sand rammed in tight, which can be easily perforated by a pointed bar, at the time of casting. The space between the top of the dam and the tymp arch is also stopped with sand or brick, a small passage being left for the

At either side of the tymp there are often fixed to the hearth casing a series of cast-iron plates with vertical racks or notches, which form points of support or fulcra for the heavy tools used in clearing the hearth and other operations in the interior of the furnace; these are known in France as *gendarmes*.

Figs. 7 and 8, which are modified drawings of a South Staffordshire furnace, represent the general arrangement of the hearth of the blast furnace mentioned in the preceding paragraph. Fig. 7 is a front view of the exterior of the hearth, and Fig. 8 a section on the line A B; *a* is the dam in section, *b* the cast-iron dam-plate, *c* the tap-hole, *d* the water tymp in elevation in Fig. 7, and in section showing the water passages in Fig. 8; *e* is the blast main, and *f* a smaller pipe supplying water to the tymp and twyers.

Details of the Top of the Furnace. The upper end of the stack, or throat of the furnace, is surrounded by a platform or charging plate sufficiently broad to give room for working the barrows used in filling ore, fuel, and fluxes. In the older square-stacked furnaces, sufficient space for this purpose could usually be found between the ring wall and the external casing; but in the more taper cylindrical or conical forms of modern

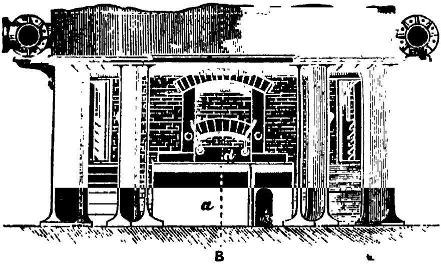

Fig. 7.—Lower part of blast furnace, showing part of hearth and dam plate.

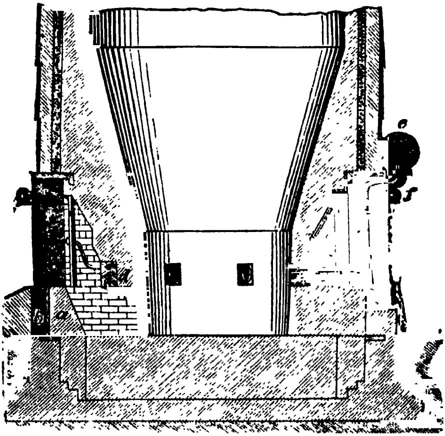

Fig. 8.—Lower part of blast furnace, section through hearth and dam.

times, additional surface is necessary. This is provided by an overhanging gallery carried upon brackets, constructed entirely of cast and wrought iron. When two or more furnaces are placed adjacent to each other, their galleries are united by bridges, which communicate with the lifts for bringing up materials to the furnace top.

When the gases are allowed to burn at the throat, it is necessary to provide a chimney in order to carry the flame clear of the charging place. For this purpose a short cylinder of brickwork hooped with wrought iron, or even of cast iron, is used, known as the *tunnel head*. The charging holes are rectangular apertures, varying in number with the diameter of the throat, in the lower part of the tunnel head, through which the charges of ore, fluxes, and fuel are introduced. Except at the time of charging they are generally closed by wrought-iron shutters.

The arrangements of the head of the furnace when the gases are collected are somewhat more complicated, and will be described further on.

Lifts. In hilly countries, where the valleys are deep, it often happens that blast furnaces can be placed below the general level of the ground, supplying the ores and fuel, so that all materials necessary for working may be delivered at the furnace top without any special appliances. In flat ground, on the other hand, such as prevails in most of the iron districts of England, it becomes necessary to resort to mechanical lifts for raising the charges. The following are some of the forms more generally employed.

Inclined Planes. These are mostly to be found in old works, the more directly vertical lift being generally preferred at the present day. They are usually made with a double line of railway, or with a single line and crossings for the return trucks, carried on trestle work. The inclination is usually not more than 25 or 30 degrees. The most convenient form of truck is a triangular frame, with two pairs of wheels of unequal height, supporting a horizontal platform of sufficient size to carry four or more of the iron wheelbarrows used in charging, with their loads. The motive power is usually a steam engine of from 10 to 20 horse power, working a pair of winding drums. The load is drawn either by wire ropes, or in Staffordshire by flat-linked chains, such as are used in the same district for drawing in collieries.

At the Barrow Iron Works, in Lancashire, two inclined planes are used for the supply of seven furnaces. They are carried by bow and string girders of wrought iron, and extend from the ground to the top of the furnace, with only one intermediate support. The platform waggon, carrying the barrows, is received into a recess in the charging platform, and a similar one below, so that the barrows with the loads may be wheeled on and off on their arrival at either end. The motive power is a high-pressure steam engine placed behind the furnaces, working a wire-rope drum. About 4,000 tons of materials are lifted weekly by each plane.

The most approved form of lift, where large quantities of material have to be raised to a considerable height, is a cage moving between vertical guides exactly similar to those used in collieries. As the load is comparatively quickly raised, it is a useful precaution, where steam power is used, to have no self-acting valve gear, but to let the engine be entirely worked by hand, in order to prevent the chance of accidents from overwinding.

The water balance is an old and favourite form of lift for small furnaces. It consists of two cages moving vertically and guided, united by a rope or chain passing over a guide pulley; below the floor of each cage is fixed a water-tight box, provided with a discharge valve in the bottom. When the empty cage is at the top of its stroke, water is allowed to flow into the box until the weight is sufficient to pull up the other cage with a fresh load, the speed being regulated by a brake on the guide pulley. As soon as the return cage reaches the ground, the projecting stalk of the discharge valve strikes against a catch, and is driven up, leaving a passage for the water, which runs out, and the cage is ready for another ascent when loaded. The chief merit about this plan is its extreme simplicity and the large useful effect got from the water, especially if a natural fall can be used, otherwise it must be pumped up by special machinery. The principal objection to it is the difficulty of keeping the water boxes tight, the lift houses being generally damp and sloppy from leakages.

A more perfect kind of hydraulic lift is that constructed upon Sir William Armstrong's system, where the lifting cage is connected to a water-pressure engine by means of a chain passing over a system of compound pulleys, so that when the engine makes a stroke of 6 or 8 feet the load is lifted through a height six or eight times greater, according to the multiplying purchase of the tackle.

Pneumatic lifts are now used to a considerable extent in England, as the necessary power, compressed air, may be readily obtained from the main blast engines supplying the furnaces. The simplest form is a wrought-iron cylinder, open at the bottom and closed at the top, about 6 or 8 feet in diameter, and somewhat longer than the height of the furnace, suspended in a tank by counter-balance weights passing over pulleys in a manner exactly similar to an ordinary gasometer. A pipe for the admission of air at 3 or 4 lbs. per square inch above the atmospheric pressure, is introduced through the tank. The waggon to be lifted is carried on the top of the bell, and as the whole of the moving parts of the apparatus are balanced, the amount of power required is only that necessary to raise the additional load. For the return stroke, the air within the bell is allowed to escape by opening a valve communicating with the atmosphere, the weight of the empty waggon being sufficient to lower the bell in the tank.

In Gjers' pneumatic lift, which is much used in the newer Cleveland furnaces, the motive power, instead of being taken from the main blast engine, is furnished by a pair of double-acting air-pumps, the lift being effected by the pressure of the atmosphere acting against a vacuum in a cylinder, while the empty waggons are returned by compressing air under the piston.

The Jacob's ladder, or endless chain system of lift, usually described in older works, is probably no longer in use.

Blowing Machines. The use of cast-iron cylinder blast engines has almost everywhere superseded the ruder contrivances of wooden chests with square pistons, bellows, &c. In Sweden, for small furnaces and forges, the single-acting form of engine is much used, being cheap and economical in working and maintenance. Usually three inverted vertical cylinders are employed, of about 3½ or 4 feet diameter and length of stroke, carried on cast-iron or wooden standards, and driven directly by a water-wheel.

The cylinder is provided with an air-tight piston, to which a reciprocating motion is imparted by appropriate mechanism. Two sets of valves are placed on the cylinder cover: the longer series open inwards as the piston recedes, giving a passage for the admission of the external air, and at the change of stroke are closed by the compressing force exerted by the piston on the included air; and the second series, or discharge valves, which are in connection with the blast reservoir, open, and allow the compressed air to pass out. In the single-acting engine only one end of the cylinder is covered and provided with valves; while in the double-acting form (represented in Fig. 9) both ends are similarly arranged, so that one side of the piston is drawing air through the intake valves, *a*, while the other is compressing the volume taken in at the preceding stroke, and driving it over into the reservoir through the discharge valves, *b*.

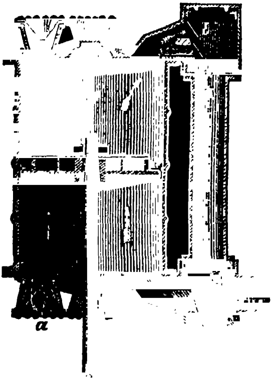

Fig. 9.—Cylinder blast engine.

The valves employed are generally oblong rectangular plates, with their shorter sides placed vertically—one of the long sides forming the hinge. In order to combine rigidity with lightness, it is usual to make them of a combination of thin sheet iron, with contact surfaces of felt, leather, or india-rubber. The hinge may be either of metal, accurately fitted, or merely a flexible leather flap. The seats or boxes to which they are affixed are usually rectangular tubes projecting from the outer face of the cylinder cover. In order that the valves may close by their own weight when relieved from the pressure of the air, it is usual to fix the beating face of the seat in an inclined position, or counterbalance weights or springs of steel or india-rubber may be used for the same purpose.

As the motion of the valves is similar to that of the pendulum, the time required for opening and shutting them is dependent on their vertical length, so that the piston cannot be driven beyond a certain speed, unless mechanical means, capable of being increased *pari passu* with the speed of the engine, be employed. This has been attempted in the so-called slide-blowing engines, where the flap valves are replaced by a slide similar to that used in steam engines, which travels at the same rate as the piston, and places the apertures at either end alternately in communication with the external air and the blast reservoir. The system of construction has been adopted at different times both in England and on the Continent. The best-known form is Slate's engine, where the slide is annular, and placed outside of the vertical blast cylinder, receiving motion by means of a pair of parallel rods connected with the rotary shaft of a steam engine below. The form of the slide is the solid of revolution produced by the rotation of an ordinary ⌒ shaped slide valve about a vertical axis, formed by the centre line of the steam and blast pistons. In Thomas and Laurent's arrangement the cylinder is horizontal; the air passages are of a rectangular form, and are, together with the slide, placed laterally in the same manner as the steam ports and slide valve in an ordinary horizontal steam engine.

In Fossey's engine, which was exhibited in the Belgian department of the Exhibition of 1862, the slide valves are replaced by discs with radial perforations, which are put in slow rotary motion by gearing from the fly-wheel shaft. A jacket is cast round the cylinder, with an interspace forming the passage from the cylinder to the reservoir. The apertures in the disc are sixteen in number, a corresponding series being formed in the cylinder ends, which are alternately opened and closed by the rotation of the disc in conformity with the motion of the piston. In the former position the external air is admitted, while in the latter the volume enclosed is driven over into the jacket and reservoir. In practice the use of the slide blast engine has not been found to be advantageous, owing to the large amount of mechanical effect consumed by the friction of the slide against the rubbing face of the cylinder, which would be great in itself, on account of the high speed at which they require to be driven, but is materially increased, owing to the dusty state of the atmosphere almost unavoidable in iron works.

In the ordinary form of engine with flap or clack valves it is necessary to provide as large an area of air ways as can be got out of the surface of the cylinder cover. The intake passages should be made, if possible, equal to one-half, and the outlet about one-eighth, of the area of the piston. As it is impossible in large engines to use single valves of these dimensions, on account of their weight, and consequent liability to give rise to injurious shocks in working, it is customary, therefore, to employ a number of small valves, whose united areas make up the required amount of surface.

The question of the relative advantages of horizontal and vertical blast cylinders has been discussed at considerable length by engineers, both in this country and on the Continent. As in many other matters depending upon practical experience, there is much to be said on either side. For engines of small dimensions the horizontal form is cheaper, and may be worked with the least amount of clearance from the vertical position of the cylinder covers, which may be pierced through like a gridiron, giving a bearing for the valves, without any overhanging parts or valve boxes. The required foundations may also be less massive than in the vertical form, owing to the longer bearing of the framing, when a horizontal direct-acting steam engine is the motor; this, of course, necessitates the comparatively larger surface for the engine-house. On the other hand, the difficulty of lubrication is increased, as the powdered graphite, which is generally used for this purpose, instead of being uniformly distributed round the pistons, is apt to fall to the bottom of the cylinder, while the upper side works dry, and the cylinder wall is worn irregularly, and becomes ovalised. The difficulty of keeping the weight of the piston off the bottom, and producing the same kind of unequal wear, is also urged against the use of large horizontal cylinders; but this objection, which has also been applied in the case of horizontal steam engines, does not appear to be productive of any practical disadvantage in the larger modern engines used for screw propulsion, whose diameters are quite equal to those of the average of blast cylinders.

In regard to vertical beam engines the chief disadvantages are their great length and expensive character of construction, and the extra amount of clearance, equal to the volume of the valve boxes, rendered necessary by the horizontal position of the cylinder covers; on the other, they have the great advantage of stability, and may be made of any dimensions; thus, in South Wales, engines are in use with blast cylinders up to 12 feet in diameter. In engines giving small volumes of blast at very high pressure, such as are used in Bessemer's process, the valves require to be made extremely light: the construction employed in such cases is a plain ring or plate of india-rubber covering a perforated plate, which opens and shuts by its own elasticity when exposed to, or relieved from, pressure.

In Coulthard's blast engines the air passages are circular holes in the cylinder, similar to those used by Bessemer, but the valves are light wooden balls covered with india-rubber, which are arranged on inclined and grooved seats, sloping in a direction contrary to that of the current of air, so that when the pressure is sufficient to drive the balls up the incline the air way is opened; but as soon as it is relieved, they roll down again, and stop the passage.

The combination of the blast and steam cylinders, when steam power is used, is effected in various ways. The large vertical engines of modern date in this country are beam engines, the main bearing being supported either on the engine-house wall or on an entablature carried by cast-iron columns. The piston-rods are attached by the ordinary parallel motion. On the steam side, the beam is often continued beyond the point of articulation of the piston-rod, and turned upward into a short crane neck, to the end of which the connecting-rod working the fly-wheel is attached. This arrangement permits the use of a long light connecting-rod, without unduly increasing the surface occupied by the engine.

In Belgium, direct-acting engines with vertical cylinders are much used, the blast cylinder being placed uppermost. In an engine of this class built at Seraing, Evans's beam, with an oscillating centre, is adopted, in order to keep the working parts within a comparatively small space, the length of the base of the engine-house being little more than the radius of the fly-wheel, or about 25 feet. The height, owing to the two cylinders being placed one above another, is considerable, being not less than 40 feet. The steam cylinder is 41½ inches, and the blast cylinder 66 inches; the length of stroke 88 inches. When working with steam of 30 lbs. pressure, and blowing air at 4½ lbs. above the atmosphere in sufficient quantity for a large furnace burning coke, the work done is equal to between 80 and 100 horse power. In the newer kind of engines built at the same works, the vertical direct-acting form is preserved, but the piston-rods are guided by sliding blocks instead of the older and more complicated arrangement of Evans.

In Austria a class of small direct-acting engines of the same character is used for charcoal furnaces, having the steam cylinder placed uppermost, which, together with the framing for the guides, is bolted on to the top flange of the blast cylinder. They are usually of small dimensions, averaging from 25 to 30 horse power, and delivers from 2,300 to 2,500 cubic feet of air per minute.

In Siegen, and other parts of Rhenish Prussia, horizontal blast engines are preferred. The commonest pattern has both cylinders placed in the same line; the rod which carries the two pistons goes through both covers of the blast cylinder, and is guided on either side. Usually two engines are coupled together upon the same fly-wheel, but the construction is such that they may be disconnected if only the power of one engine is wanted. For charcoal furnaces from 30 to 40 horse power is considered sufficient, but with the larger ones, working on coke, from 80 to 100 horse power is found to be necessary, as in other districts.

The same kind of horizontal engine is generally adopted in new works in Sweden and Lapland, having only a single charcoal furnace.

The working limits of blast pressure vary with the nature of the fuel employed, and the burden of the furnace, &c. Thus, in some of the small charcoal furnaces of Northern Europe, it does not exceed half or three-quarters of an inch of mercury above that of the atmosphere; while in American anthracite furnaces as much as 15 inches, or 7½ lbs., is used. In England from 2½ to 3 lbs. is used with cold blast and tender fuel, but 3½, 4, or 5 lbs. is common with hard coke. In Bessemer's process of steel-making, by forcing air through a column of molten pig iron, a pressure of from 15 to 20 lbs. per square inch is used.

The largest blast engines hitherto constructed are those at Dowlais and Ebbw Vale, in South Wales; the former, which was erected by the late Mr. Truran, has a cylinder 144 inches in diameter, with the same length of stroke; the area of the admission valves is 56 square feet, that of the discharge valves 16 square feet, the former being equal to half the surface of the piston. The steam cylinder is 55 inches in diameter, with a piston making a stroke of 13 feet, the motion being transmitted by an unequal-armed beam. Owing to the large area of the air ways a very high speed, as many as 20 strokes per minute, can be obtained. The volume of blast delivered is about 51,000 cubic feet, at a pressure of 3½ lbs., sufficient for the supply of six large furnaces and four refineries. The main blast pipe is 5 feet in diameter. The Ebbw Vale engine has a blowing cylinder of the same size, but the steam cylinder is 72 inches in diameter.

The practice of blowing several furnaces by one engine of large size, though mechanically advantageous, is attended with considerable risk, as the safety of the furnaces may be endangered in the event of a breakdown, unless there be a reserve of blowing power. It is therefore preferable to divide the work between two or more engines, according to the number of furnaces in blast. Where there is only a single furnace, as is usually the case in charcoal-smelting, two small engines coupled together, but capable of being worked independently of each other, may be used, for the same reason.

Blast Regulators. The air or blast issues from the blowing cylinder in an irregular stream, owing to the variation in pressure at different points of the stroke, the supply being intermitted during the period of actual compression after the closing of the intake, and before the opening of the discharge valves. In order, therefore, to produce a steady current in the furnace, it is necessary to use some means of equalising the pressure. This may be done either by receiving the blast into a reservoir whose volume is several times that of the blowing cylinder, or by delivering it into a second cylinder containing a loaded piston, which rises when the supply of blast is greater than the amount required by the furnaces; but when the quantity diminishes the piston falls, and exerts a compressing force, until the equilibrium is restored by increasing the speed of the engine. The same effect may be produced, with less loss from friction, by the use of a loaded bell, or gasometer, floating in a water tank.

The volume of these regulators may be from one and a half to twice that of the blast cylinder.

Fixed reservoirs are usually made of wrought iron; formerly a spherical, or balloon-shaped form was commonly adopted, but they are now more generally made cylindrical, with flat ends like high-pressure steam boilers. The thickness of the plates, of course, depends upon the pressure and dimensions employed, as well as the form adopted: from one-twelfth to one-eighth of an inch may be taken as sizes commonly used. The volume of the regulator may be from twenty-five to fifty times as great as the amount of blast in cubic feet delivered by the engine per second, when it is placed near the furnace, but this may be considerably diminished when a long blast main is used. Indeed, it often happens that sufficient uniformity can be got in the latter case, especially when several engines are used, by blowing into the main direct, without the use of a special regulator.

Regulators in masonry or brickwork are usually lined with cement in order to protect the air from taking up moisture. A regulator of this character, consisting of a chamber cut out in the solid rock, was applied at Devon Iron Works, in Scotland, as early as 1792.

Blast Heating Apparatus. The use of heated air in the blast furnace, which was first introduced by Neilson in 1828, has been found to be attended with a great economy of fuel, and at the same time the working power of the furnace is increased. It is therefore employed at the present day in iron-making districts all over the world, almost to the exclusion of cold blast, the latter being retained only for certain special makes which command an extra price, and may there-

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The amount to which the temperature of the blast may be raised with advantage does not appear to have any practical limit, every fresh increase being attended with further saving of fuel; thus, in the first instance, 100° were found to be an advantage over air at the ordinary temperature; then came temperatures of 200°—400°, up to the melting-point of zinc; and now it is actually used at a visible red heat, or about 700°. Thus it was found that a saving was produced of 5 cwt. of coke per ton of iron made by using air heated to about 650°, instead of the lower temperature of 350° or 400°, previously employed. The difficulty of keeping the apparatus tight, and the rapid destruction of metal pipes when heated to redness in air, render a special construction necessary for the production of such extremely hot blast economically.

The greater number of blast-heating apparatus in use at the present time, and known as *hot blast ovens* or *stoves*, consist essentially of a series of parallel, or spiral tubes, arranged in a chamber of fire-brick, and heated externally by a fire. The opposite ends of these tubes are connected with two mains intersecting them at right angles. One of these supplies cold air, while the other, or hot blast main, removes the heated air.

In the older forms of stove, such as that originally adopted at Calder, in Lanarkshire, the fireplace is an oblong rectangle in plan. The two mains, which are placed parallel to the longer sides, are of a circular section, and cast with a number of circular sockets for the heating pipes. These are arched. horse-shoe, siphon, or inverted **U** pipes, also circular in section, placed with the arched portion upright, and luted into the sockets on the mains. The fire-grate runs along the whole length of the bottom, and the flame, after playing on the under sides of the tubes, passes between and around them, by means of appropriate flues, into the chimney, while the cold air, entering by the main on one side, flows continuously through the arched pipes, where it becomes heated, and passes off to the furnace by the opposite main.

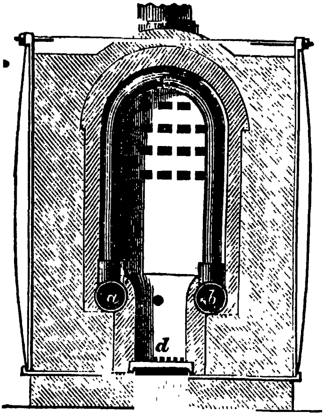


Fig. 10.—Hot blast stove. Dowlais. (Truran).

This arrangement is shown, in Fig. 10, in section across the shorter side of the stove: *a* is the cold blast main; *b* the hot blast main; *c* the arched heating pipe set in sockets on the two mains; and *d* the fire-grate.

To obviate the defects of this apparatus, many special modifications have been introduced. Thus, in order to get a greater amount of heating surface, the horse-shoe pipes are now usually made of flattened elliptical, or rectangular, instead of circular section. A smaller radius of curvature for the arch has been obtained by the use of inverted **V** pipes, and more uniformity in heating, by the introduction of stops at intervals in the entry main, so that the air is made to pass alternately backwards and forwards several times across the arch, instead of moving only in one direction, as was the case in the original form.

Whatever system of construction is used, the air should pass through the apparatus in the reverse direction to the flame, entering cold, at the end farthest from the hottest point of the fire.

Arch-headed pipes are very easily broken by irregular expansion at the crowns, if a certain freedom of motion is not allowed to the ends; this is equally provided against by placing one of the mains loose on its bed, supporting it by spherical bearings, so that it may travel outwards to a slight extent as the pipes become heated.

Round and oval ovens have been introduced to obtain a more uniform heat than can be got by the old rectangular form. These terms refer to the shape of the base, or fireplace. The mains are replaced by a cast-iron box of a square or trapeziform section, divided by a central partition, one division corresponding to the cold, and the other to the hot blast main. The vertical pipes, instead of being arched at the top, are united by a short horizontal one, the limbs being close together. This variety is much used in Staffordshire and Lancashire.

A modification somewhat similar to the last, known as the *pistol pipe,* is used in Scotland, Cleveland, and other districts in this country, and is also rather in favour in France and Germany. The two vertical pipes or limbs are replaced by a single one, divided by an internal partition reaching nearly to the top. It is closed at the upper end, and is either straight, slightly bulbed, or bent over into a half arch. One of the divisions is connected with the intake, and the other with the exit, so that the cold air rises on one side, and passes through the bulbed chamber at the top, down the other, heated to the furnace. When the curved head is used, it is usual to place two series of pipes in opposite directions with the heads, meeting so as to form an arch for mutual support; but, of course, the question of unequal expansion does not arise, as each half of the arch is independent of the other. The term pistol pipe is derived from the resemblance of the curved head to a pistol stock, the straight portion corresponding to the barrel. This construction is represented in Fig. 11, the left-hand pipe being shown in section, and the right-hand one in elevation.

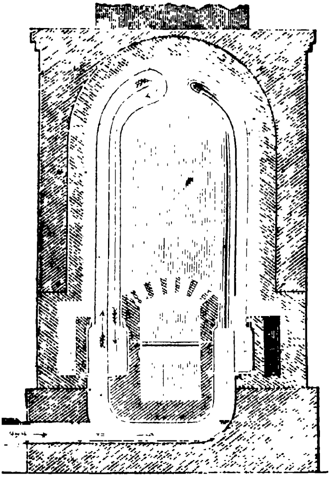


Fig. 11.—Pistol-pipe hot blast stove. Oberhausen.

All the preceding forms of stoves are characterised by the use of air ways presenting continual changes of form; thus the blast passes from the main through the heating pipes alternately backwards and forwards. In what are known as spiral-pipe ovens, the heating is effected in tubes of uniform section, arranged similarly to the worm of a still. Among these may be mentioned the apparatus in use at Ebbw Vale, a horizontal coil of cast-iron pipes exposed to a fire running the whole length of the axis. The pipes are formed in segments corresponding to one-half of a complete turn of the screw, and are united by ordinary socket joints.

The union of the pipes and mains in stoves is always effected in the same manner, the latter being cast with sockets for receiving the ends or feet of the pipes, which are often made slightly conical, spigot fashion. The joint is made air-tight by rust cement.

Stoves with straight or serpentine horizontal pipes are much in vogue in Germany, and are known after the name of the works at Wasseralfingen, in Wurtemberg, where they were first introduced. In the original construction a number of straight pipes of circular bore, placed horizontally, extend from side to side of the walls of the fire chamber in a manner exactly similar to the tubes of a locomotive, and are united into a continuous serpentine coil by external arched bends not exposed to the fire. In this way the difficulty arising from the tendency of the pipes to break at the bends, owing to irregular expansion when heated, is avoided. The newer forms differ chiefly from the foregoing in the section of the pipes, which are now usually elliptical instead of circular. The position of the longer axis may be either horizontal or vertical; the latter, being the most advantageous arrangement, is usually adopted.

Fig. 12 is a section of a stove of this pattern at Neustadt, in Hanover. The coil consists of four pipes united by semicircular bends, four similar series being united by other bends placed horizontally, so that the whole apparatus contains sixteen pipes. The cold air enters at *c*, and passing downwards, issues in a heated state at *d*. The fuel employed is the waste gas from the blast furnace, which is supplied through the wrought-iron main, *a*, and jet-pipe, *b*. The latter is provided with a central tube for the admission of the air necessary for burning the gas.

Thomas and Laurent's stove, used in several of the newer French furnaces, consists of three vertical tubes of large diameter, united by external horse-shoe pieces placed externally, as in the Wasseralfingen apparatus.

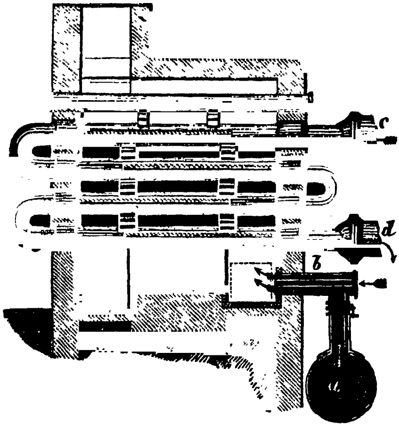


Fig. 12.—Hot blast stove. Wasseralfingen pattern.

In order to obtain a larger heating surface, the inner side of the tube is studded with projecting radiating ribs about 3 inches high, the remaining interior space being filled with a cylindrical core of cast iron or fire-brick. These ribs are not continuous in the same place throughout the entire height of the tube, but are interrupted at different levels, the series above and below being arranged so as to break joint with the central one. By this means the air is forced to travel in a somewhat deviating course through the passages enclosed between the core and the ribs. A very considerable heating effect is claimed for this arrangement, which is similar to that of the stoves known as "gill calorifiers," used for warming large rooms; but it is attended, owing to the irregular section of the air ways, with a notable loss of pressure from friction.

In considering hot blast stoves, we have hitherto assumed that the heating of the air is to be effected by means of fuel burnt on a grate below the pipes. This is still done to a considerable extent, but the substitution of the waste gases of the furnace is now almost equally common, especially in furnaces using fuel brought from a distance. For this purpose it is necessary to bring a branch pipe to the stove from the main gas conduit, which terminates either in a series of jets, or more commonly in a rectangular mouth-piece, a special aperture of a similar character, foi the admission of air, being placed immediately above or below.

It is generally advisable to have a grate with a small fire, which insures ignition of the gases; without this, in case of the flame becoming extinguished, air would be liable to get back into the gas main, where it would most probably produce an explosion.

Cowper's stove, for heating air to very high temperatures, is constructed on the so-called "regenerative" principle of Siemens. It consists, as shown in section, Fig. 13, of a cylindrical chamber, with a low-domed roof of fire-brick work, cased with wrought iron; the discharging passage for the hot blast, made of similar materials, projects on one side, opposite to which is the stack for producing the necessary draught.

In the interior of the chamber a vertical shaft, A, whose diameter is about one-third of the whole space between the walls, extends from the floor nearly to the roof, and communicates at the bottom with the passages, B, by which the inflammable gases and air are admitted, and by a horizontal flue, C, with the hot blast exit passage. The annular space between the central shaft and the walls of the chamber contains two parallel ring flues; these serve alternately for the admission of cold blast, and the escape of spent flame to the chimney. Above these flues, which occupy about a quarter of the total height of the chamber, the whole of the remaining space, up to the springing of the dome, is filled with fire-bricks loosely stacked, so that a large number of small rectangular openings are left between them, forming the channels for the blast and gases to circulate. During the time of heating, the hot and cold blast valves, E and F, are shut, and the gas and air valves, G and H, below the central shaft, opened. The ignited gas then rises up the shaft, and passes downwards through the bricks and lower ring flues into the chimney, the draught being regulated by a special damper.

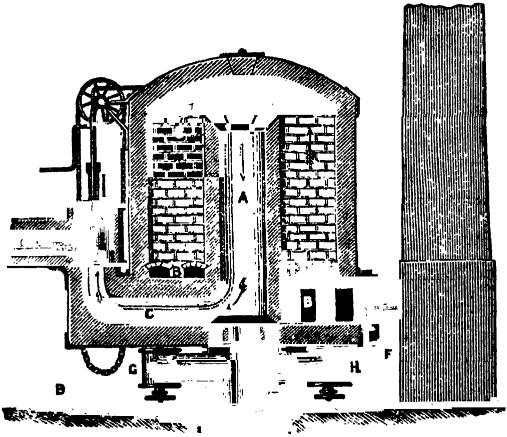


Fig. 13.—Cowper's hot blast stove.

The heat evolved by the burning gases is transferred to the bricks, the temperature of the layers being increased progressively from above downwards, until, in about two hours' time, the whole contents of the chamber are brought to a uniform strong red heat; the air, gas, and chimney valves are then closed, and the cold blast is admitted by the valve, F, and passes through the chamber in the reverse direction to the heating current, upward through the bricks, abstracting their heat, and down the central shaft through the hot blast valve, E, to the furnace. The current of cold air is continued until the bricks, with the exception of a few of the upper layers, are no longer red-hot; the blast is then stopped, and the heating is recommenced by admitting gas and air as before. It is of course necessary to have two stoves in order to keep up the blast continuously, one being heated while the other is cooling, and *vice versâ*. By this system of stove the gaseous fuel is very perfectly economised, the temperature of the current in chimney being not much above that of boiling water, 100° to 120°, while the blast is made visibly red-hot, and capable of melting antimony with ease, corresponding to a temperature of 700° to 800°. In this stove all the parts brought into contact with the heated air are made of refractory brickwork, with the exception of the hot blast valve, which is of cast iron, with double walls, and cooled with water like an ordinary hot blast twyer.

Fig. 14, taken from Tomlinson, shows the course of the air and gas in a pair of these stoves when at work. The right-hand one is being heated, while the other is giving up its acquired heat to the blast. Fig. 15 shows the manner in which the bricks are stacked in the regenerators.

A simple form of the stove last mentioned has been recently introduced by Whitwell. In it the cellular piles of bricks are replaced by plain walls; the former method of construction being objectionable when blast-furnace gas is used for heating, as the spaces between the bricks are liable to become choked by the deposit of flue dust. The oven or heating chamber is enclosed by four upright walls, and divided by internal, upright, parallel partitions into several narrow compartments.

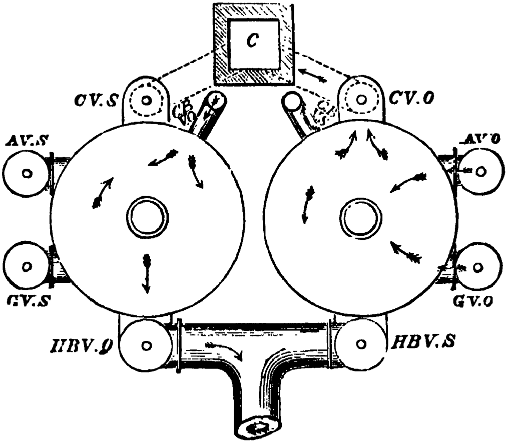


Fig. 14.—Cowper's hot blast stove plan.

C. Chimney.
C.V. Chimney valve.
G.V. Gas valve.
S. Shut.
H.B.V. Hot blast valve.
A V. Air valve.
C.B.V. Cold blast valve.
O. Open.

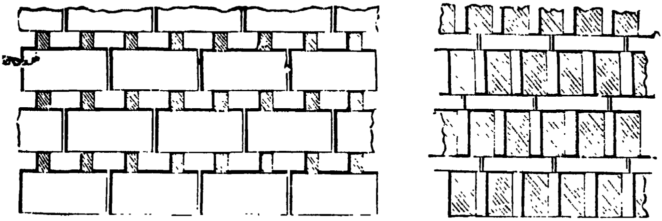


Fig. 15.—Cowper's hot blast stove. Details of arrangement of bricks

Fig. 15* represents Whitwell's stove, as applied to a blast furnace at Consett. It is one of four, each measuring 22 feet in diameter, by 25 feet high, and containing 9,000 square feet of heating surface, or 36,000 feet in all.

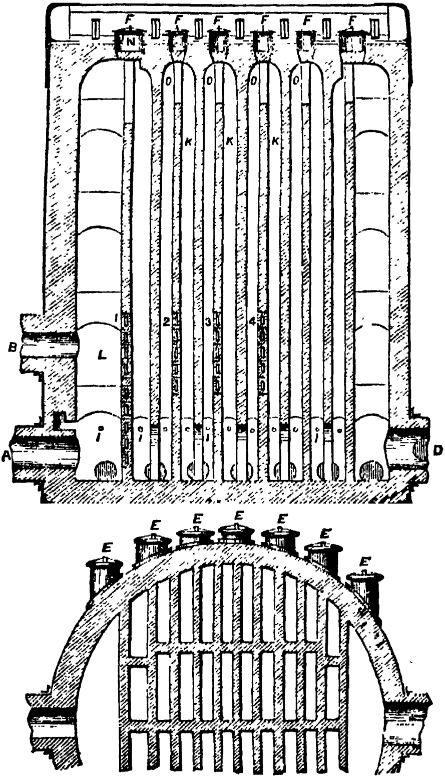


Fig. 16*.

The stove is circular in form. The gas enters at B, sufficient space being allowed at the hot end, L, for the ignition of gas by air admitted through the cellular passages 1. The flame is conducted through the stove by conduits, O K, 9 inches broad, the average width of the passages in a transverse line across the stove being about 15 feet, thus giving a total length of flue of 240 feet, with a section of 11¼ square feet, care being taken so to place the arches, O, above and below the alternate walls, that the gas may be equally distributed. Other air passages are placed at 2, 3, and 4, in order to ensure perfect combustion of the gas.

Of the 240 feet of travel, or 9,000 square feet of surface, about two-thirds, 180 feet and 6,000 square feet respectively, are raised to a bright red heat, as seen through the eye-pieces, I I, perforating the casing and shell, by which the state of the interior can be readily observed. In the remaining space of one-third the temperature shades down gradually, until the products of combustion pass off to the chimney, C, where their temperature is reduced to about 300°. When the stove has been heated to this point, the gas-inlet-valve, B, and chimney-valve, C, are closed, as well as all the air-valves, 1, 2, 3, 4, and the hot and cold blast valves, D and A, are opened. The cold blast now enters at D, and passing over the walls in reverse order to the gas, commencing at the coldest end, is gradually heated until it attains the temperature of the hottest surface, when it passes through tubes lined with 9-inch brickwork, and enters the blast-furnace at a visible red heat, about 650°. Of the four stoves, Nos. 1 and 3 and 2 and 4 are worked in pairs, the blast being on the former while the latter are heating. The hot-blast main is 3 feet in external diameter, giving a clear airway of 18 inches within the 9-inch fire-brick lining.

The blast is allowed to pass for two hours, by which time only one-third of the whole surface remains at a red heat, below which it is not allowed to cool, in order to ensure regularity in the working of the furnace.

At the hot end, L, the first walls are constructed half of ganister, and half of fire-brick. The transverse walls, which are 7 inches thick, are built in lumps, 12 inches by 7 inches by 3 inches. All the brickwork is carefully laid, the joints being perfectly flushed up with fire-clay. The weight of brickwork in each stove is 298 tons. The hot blast and gas-valves are of cast iron, with a hollow space between the sides, through which, as well as through the seatings, a current of water circulates, care being taken to prevent the blast from impinging directly upon the cooled surfaces. When it is desired to clean the stove, the gas having been shut off and the chimney-valve slightly opened, in order to carry the heat downwards, the first top cleaning-door, F, at the hot end is taken off, and the movable plug in the crown of the arch, N, lifted. Scrapers with $\frac{3}{4}$-inch tubular handles, screwed together to attain the right length, are introduced, and the walls on either side are scraped down, the dust falling to the bottom. The compartment being thus cleaned, the door is replaced and luted with fire-clay, and the same process is repeated with the doors in rotation while the walls are red hot. The side doors, E, at the bottom are then opened, and the dust detached from the walls is raked out. The operation, which takes about nine hours, is repeated every two or three months, according to the amount of dust brought over by the waste gases.

In the construction of the stove, a space of 1 inch is left between the brickwork and the wrought-iron casing, which is filled with dry clay or granulated slag, so as to allow for any expansion of the brickwork. A similar allowance is made at the top.

By the use of these stoves a very considerable saving has been effected in the consumption of coke per ton of pig iron made, on account of the very high temperature of blast obtained. The furnace to which they have been applied makes 400 tons weekly, with a consumption of 17½ cwt. of coke per ton. The charge contains two-thirds calcined Cleveland stone and one-third red hematite, yielding about 48 per cent. of iron. The blast is heated to 730°, and temperature of the gases at the top is 250°. An adjoining furnace of the same size, and working on the same ores, with a blast heated to 450°, consumes 22½ cwt. of coke to the ton, and gives off the waste gases at 470°.

The amount of heating surface in hot blast stoves with cast-iron pipes is usually about one square foot per cubic foot of blast passing through per minute when fired with coal. With gaseous fuel it is advisable to make them from 10 to 20 per cent. larger.

Pressure Gauges. For low-pressure blast, such as is used in small charcoal furnaces, or for determining the tension of the waste gases, a water gauge is generally used, but for the more highly compressed air used in furnaces on mineral fuel, mercury gauges are necessary. When the blast is at a very high temperature, it is necessary to make the observations as quickly as possible, or to cool the air down by passing it through a tube placed in a current of water, before allowing it to come in contact with the mercury. By multiplying the indications of the mercurial gauge in inches by 13·59, the corresponding height measured in water is obtained, and conversely, inches of water gauge may be reduced to mercurial inches by dividing by the same constants. When, as is usually the case, the height of the water gauge is expressed in feet and inches, it may be reduced to the corresponding pressure in inches and lines of mercury by multiplying by 0·882. The amount of blast passing through a twyer is found by multiplying the velocity of the current passing per minute or second, as deduced from the pressure, by its sectional area. The result must, of course, be corrected for temperature, atmospheric pressure, and moisture, and for the contraction of the jet at the point of efflux. The latter correction varies in amount with the form of the nozzle, and is somewhat greater for cylindrical than conical pipes, and also increases with the pressure employed. As a general rule, the diminution of volume from this cause may be taken at about 8 per cent., and the real amount found by multiplying the theoretical quantity by 0·92.

The determination of the amount of blast carried into the furnace, from the observations given above, may be approximately found by the following formula, given by Weisbach, as a simplification of the more exact one deduced by him from Poisson's law, checked by actual experiment:—

$$Q = 1179\,F\sqrt{\frac{h}{b}} \cdot \sqrt{\frac{1{\cdot}018}{1 + 0003672\,\tau}} \qquad (1)$$

where Q = the number of cubic feet discharged per second, reduced to the temperature of 10° Centigrade, and 30 inches barometrical pressure, F = area of twyer, h = observed height of pressure gauge in inches of mercury, b = observed height of barometer.

The second part gives the correction for the heat of the blast, when τ = its temperature in Centigrade degrees.

In the first part of the above formula, F is taken in square feet, by dividing by 144, or, putting F = 1 square inch, we obtain the following simple expression:—

$$Q = 8{\cdot}2\sqrt{\frac{h}{b}} \qquad (2)$$

which gives the volume of blast per second per square inch of the sectional area of the twyer. The following table gives the value of Q for different values of the fraction $\frac{h}{b}$ in formula (2):—

$\frac{h}{b}$	Q	$\frac{h}{b}$	Q
0·01	0·82	0·30	4·49
·02	1·16	·35	4·85
·05	1·83	·40	5·19
·10	2·59	·45	5·50
·15	3·18	·50	5·80
·20	3·67	·55	6·08
·25	4·10	·60	6·35

These quantities require to be corrected for temperature when hot blast is used by the second part of formula (1).

The quantity of air passing into a furnace may also be decided from the composition of the waste gases when the furnace works with a closed top, and the whole of the volatile products are collected.

Determination of the Temperature of the Blast. Mercurial thermometers cannot be used in determining temperatures much above 200° or 250° with accuracy, owing to the irregular expansion of the mercury when near its boiling-point. For measuring the high temperatures prevailing in blast-furnace operations, metallic pyrometers of various kinds are employed, depending either on the expansion of a single metal, or a combination of two, such as iron and copper or platinum. These, although convenient, are liable to give inaccurate results after a time, from the metals becoming permanently expanded when repeatedly heated.

In practice the temperature of the blast is generally determined by its power of fusing metals. This is done by exposing a thin rod of the metal to the current in the twyer, a hole being made for the purpose in the elbow of the branch pipe connecting the twyer with the blast main.

The following are the reputed melting-points of the metals available for determining the temperatures of hot blast:—

	Degrees.
Tin	245
Bismuth	250
Lead	330
Zinc	410
Antimony	512

In experiments on the temperature of the interior of the furnace, such as those made by Tunner in Styria, and Rinman and others in Sweden, alloys of gold and silver, and silver and platinum, are used, the increase of the melting-point being assumed as directly proportional to the increase in the amount of the more refractory metal. This method was also used by Plattner in determining the temperature of fusion of slags.

The following table contains the melting-points of various alloys used for the above purposes by Tunner:—

					Degrees.
9	Lead +	1	Silver	melts at	400
8	,,	2	,,	,,	470
7	,,	3	,,	,,	540
6	,,	4	,,	,,	610
5	,,	5	,,	,,	680
4	,,	6	,,	,,	750
3	,,	7	,,	,,	815
2	,,	8	,,	,,	885
1	,,	9	,,	,,	955
0·6	,,	9·4	,,	,,	980

					Degrees.
9·5	Silver +	0·5	Gold	melts at	1,030
7	,,	3	,,	,,	1,050
4·5	,,	5·5	,,	,,	1,070
2	,,	8	,,	,,	1,090
			Fine Gold	,,	1,100
9	Silver +	1	Platinum	,,	1,175
8·5	,,	1·5	,,	,,	1,250
8	,,	2	,,	,,	1,325
7·5	,,	2·5	,,	..	1,400
7	,,	3	,,	,,	1,475
6·5	,,	3·5	,,	,,	1,550
5	,,	5	,,	,,	1,625

Pouillet's pyrometric method, which consists in observing the increase of temperature produced in a weighed quantity of water by plunging into it a mass of metal, whose weight and specific heat are known, heated to the temperature to be measured, has also been applied to the construction of pyrometers for blast furnaces; a ball of copper is used for medium, and platinum for higher temperatures. From the increase in the sensible heat of the water, the loss experienced by the metal may be found by the following formula:—

$$t' = \frac{w\,t}{w'\,s} \qquad \text{where}$$

w = weight of water, t = its increase of temperature, w' = weight of metal ball, s = its specific heat. To this result must be added the observed temperature of the water in order to get at that of the furnace.

Siemens' pyrometer, which is used to a considerable extent for measuring hot blast temperatures, is of this kind, and is thus described by the inventor:—

"It consists of a portable vessel, formed of three concentric cylinders of thin copper plate, the space between the inner and middle one being filled with cowhair, and that between the middle and outer one with air, so as to prevent as perfectly as possible the loss of heat from the interior. A delicate mercurial thermometer is fixed in the interior of the vessel, being protected by a perforated shield, and furnished with a movable sliding-scale, showing pyrometer degrees, each of which is equal to 50° of the ordinary thermometric scale. For obtaining the temperature, balls of copper or platinum are used, which are so adjusted that fifty of them would be equal in thermal capacity to an imperial pint of water. Each ball is perforated by a hole, through which a rod is passed in exposing the same to the action of the heat to be measured. Immediately before using the instrument, an imperial pint of water is poured into it, and the slide is so moved that the zero point of its scale corresponds with the top of the mercury in the thermometer. The ball, after having been exposed to the heat for two or three minutes, is plunged into the water. The mercury will then be observed to rise, and the absolute measure of th temperature is obtained by adding the reading on the pyrometer scale opposite the new level of the mercury to the original temperature of the water before the ball was introduced. With a little practice very satisfactory results may be obtained with this instrument; but its application is limited to the heat at which the metal ball is deteriorated; nor can it be used for measuring the temperature of inaccessible places."

Another pyrometer, recently invented by Mr. Siemens, is based upon the property possessed by pure metals of offering an increased resistance to the passage of an electric current in proportion as their temperature increases.[*] A platinum wire of known resistance is wound upon a helical groove on the surface of a cylinder of fire-clay, and enclosed within a cylindrical casing of platinum if the temperature to be measured exceeds the welding point of iron, or copper for lower temperatures. The two ends of the coil are brought endways, and are attached within the tube to thicker wires of copper, insulated for a short distance by a coating of pipeclay, and further on, when beyond the influence of the heated space, by india rubber or gutta percha. These wires communicate with the measuring instrument, which may be placed at any convenient distance. The latter is a specially constructed galvanometrical arrangement, and is so graduated that a reading in degrees on a divided scale may be at once obtained. These do not give an absolute measure of temperature, but the final result is taken out from a table calculated for each instrument. The pyrometer coil may be either fixed permanently, if it is desired to have a means of continuously determining the temperature of a particular place, or it may be introduced into the furnace through a door or other opening for a minute or two, which is sufficient time to obtain a reading. The latter is the only method available for very high temperatures; for by continuous exposure the protecting case, even when of platinum, would be ultimately destroyed. The electrical resistance of platinum wire is increased fourfold by a rise of temperature from 0 to 1650°.

Position of Hot Blast Stoves. It is in all cases desirable to place the stoves as near to the furnace as is consistent with the other requirements of the works, in order that the blast may lose as little of its acquired heat as possible, by not having to travel a long distance through pipes exposed to the air. In some instances, especially in small charcoal furnaces, where the stoves are heated by waste gases, they are placed on a level with the furnace top, the gases being led in by a short flue in order to economise their sensible heat, as well as the much greater quantity derived from their subsequent combustion. The hot blast main is then carried down vertically to the twyers. This practice is tolerably common in Swedish and German charcoal furnaces, and appears to be very general in the United States, where the blast-engine boilers are often carried on the top of high-vaulted structures in the same manner. Much greater regularity of draught, and especially freedom from choking by dust, can be obtained when the stoves are placed at the ground level, and the gases are brought down by a suitable conduit.

Arrangement of the Twyers. The blast coming from the stoves passes through a ring main, which, in the old square-cased furnaces, is carried through the circular passage traversing the stack pillars; but in the newer forms is generally attached to the columns, surrounding the hearth at a certain distance above the ground. A vertical branch pipe, or *goose neck*, is led off opposite to each twyer hole, and at the proper level is turned over at right angles into a horizontal arm, to which the blast nozzle, or blowpipe, is attached.

A throttle, or slide valve, for stopping or regulating the blast, is attached to each branch, as well as to the main near the stove.

In cold blast furnaces the air is led through a conical copper nozzle, attached to a branch pipe by a flexible leather tube; but with hot blast it is requisite to make all the fittings of metal, and the necessary means of adjustment are provided by interposing a sliding or telescopic tube and a ball-and-socket joint between the end of the branch pipe and the twyer. By the former the twyer is set to the proper length, while the latter allows the direction of the entering blast to be varied, so that it be made level, plunging or rising at pleasure.

When hot blast is used, it is necessary to protect the walls of the hearth from the intense heat generated by the energetic combustion going on immediately in front of the twyers. This is done by the use of water twyers, which are hollow, conical, or tapering D-shaped tubes, with double walls, which are kept cool by a current of water circulating through the interspace.

Fig. 16 represents a hot blast twyer as applied to a charcoal furnace at Rhonitz, in Hungary. *a* is the water twyer, formed of cast and wrought iron, with double walls, which are cooled by a current of water circulating through the intermediate space. *b* is the blowpipe, which is of sheet iron, and bears against a divergent conical orifice placed within the water twyer. The latter arrangement is not usual, the end of the blowpipe being generally inserted loose in the twyer, and the intermediate space stopped with clay. The axis of the jet may be made horizontal, or to incline upwards or downwards by means of the ball-and-socket adjustment at *c*. The end of the twyer is advanced or withdrawn by the telescopic joint and setting screw at *d*. The flanged elbow-pipe fits on to the vertical branch pipe of the hot blast main. At *e* the elbow is perforated by a small hole, having a movable shutter, containing a plate of glass or mica, which gives a view of the interior of the hearth, or rather of the bright spot, or eye, immediately in front of the twyer. Through this aperture the fusible metals used in trying the temperature of the blast are introduced.

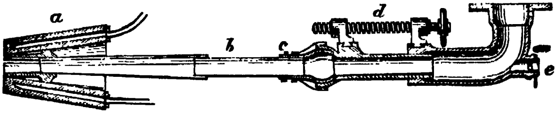


Fig. 16.—Hot blast water twyer. Rhonitz, Hungary.

Water twyers are made either entirely of cast or wrought iron alone, of a combination of both, or of copper or bronze. The water space is usually rectangular in section, but sometimes a spiral tube of wrought iron is used, either alone or set in a casing of cast iron. An advantage is claimed for bronze twyers of not being readily destroyed by "ironing," that is, of being melted by the imperfectly-fused masses of metallic iron which sometimes adhere to the end of the twyer when the furnace is not in good working order, and the reduced iron is imperfectly carburised. The removal of the adherent masses may be effected by raising the dam, and allowing the cinder to rise above the level of the twyers. Leaky water twyers are productive of great waste of fuel, owing to the large amount of heat absorbed in the decomposition of the steam produced in the hearth. The temperature in the region of fusion is consequently lowered, with the production of white iron of a low degree of carburisation. When the leak is considerable the consequences may become more serious, as the water, if it gets into the lower part of the hearth, is likely to produce an explosion.

The number and arrangement of twyers vary very considerably. The smaller charcoal furnaces have often only two, placed on opposite sides of the hearth. Three is a more usual number, one being placed at the back; *i.e.*, opposite to the tymp, and the others at the sides of the hearth. When a larger number is used, they are generally placed at equal intervals all round the hearth. This method is usually adopted in cupola furnaces; but in South Wales, where there are many large furnaces with only three twyer arches, they are sometimes arranged in series; thus, two will be put through each of the side openings, and the same number at the back, or three at the sides, and one or two at the back, &c. This is done to avoid the use of twyers of an excessive diameter, and, by multiplying the points of contact with the fuel, to make the combustion more uniform over the entire area of the hearth. Sometimes a special twyer is added on the tymp side, for the purpose of removing irregularities caused by local cooling, and is only used in case of the hearth becoming obstructed.

Methods of Collecting Waste Gases. In small charcoal furnaces, working with an open throat, the gases are often taken off by wrought-iron pipes perforating the wall of the furnace about 10 or 12 feet below the top. This plan is commonly used in Sweden for supplying gases to mine kilns, hot blast stoves, &c., but can only be practised on a small scale. The supply is apt to be somewhat irregular, from the stoppage of the holes by the descending charge. A more perfect method for the same purpose, is that of contracting the throat by the insertion of a cast or wrought-iron cylinder of somewhat smaller diameter than the ring wall, so that an annular space at the top is kept clear from the materials of the charge, and forms a collecting flue for the gases. In order to prevent the charges from blocking up the lower part, it is usual to increase the diameter of the shaft by the amount required to form the flue, and the tube restores the furnace to its original section. The application of this arrangement is shown in the charcoal furnace, Fig. 4.

When it is desired to collect the whole of the gases given off at the top of the furnace, it is necessary to work with a closed throat. The most generally used, and, at the same time, one of the simplest contrivances for this purpose is that known as the cup and cone, Fig. 17. It consists of an inverted conical cast-iron funnel fixed to the top of the furnace, whose lower aperture is of about one-half of the diameter of the throat. An upright cast-iron cone is placed in the furnace below the cup; it is suspended by a chain attached to its apex, so that it may be raised or lowered at pleasure; in the former position it bears against the bottom of the cup, and forms an air-tight stopper, preventing the escape of any gas from the top of the furnace, which then finds its way out by proper passages through the

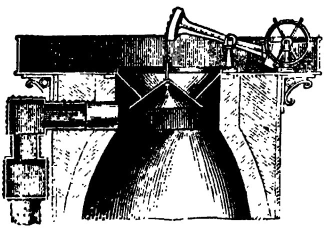


Fig. 17.—Furnace top, with cup-and-cone charger.

wall of the furnace in the space above the charges enclosed by the cup; but when lowered it allows the charges in the cup to be dropped into the furnace, and at the same time acts as a distributer. Only the small amount of gas that is lost during the time of charging is allowed to escape, and as this operation is very quickly performed, the current through the mains is kept up with great regularity. The cone is suspended by an arch-headed lever, carrying a counterbalance at the end of the opposite arm. The raising or lowering is effected by a pinion, moved by a hand-wheel gearing into a segmental rack attached to the counterbalance weight. The gas passes through a lateral flue into a square wrought-iron main pipe, or conduit, which distributes it to the various pipes feeding the boiler fires and hot blast stoves. A modification of the cup and cone is in use in Cleveland, where the cone is replaced by an external cylindrical stopper, which is lifted during the charging time, and lowered when the throat is stopped, the object being to allow the charges to occupy the space which is necessarily kept empty for working the cone on the old system. It was found, however, that the working of the furnace was injured from the want of a proper distributer for the charges, on account of the absence of the cone: when this was supplied by suspending a conical ring by three chains to the bottom of the plug, regularity in charging was restored.

In the above methods, the gas is collected chiefly from the sides of the furnace, a practice which, as will be shown further on, is not in all cases to be recommended. The alternative plan is to collect from the centre; this is usually done by inserting an iron tube a short distance down the centre of the furnace, the lower end being supported on ribs of brickwork, while the upper part is turned over in the form of a siphon, as, for example, in the furnace, Fig. 6, at p. 142. The annular opening between the tube and the ring wall forms the space for charging, an arrangement exactly the reverse of that noticed at p. 179. Only a part of the gases are collected by this method. The draught is in some cases aided by an exhausting fan. Coingt's apparatus, in use in France, is a combination of the central tube with the cup and cone.

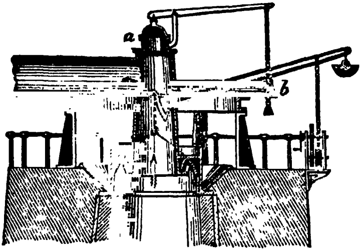


Fig. 18.—Furnace top, with Langen's charger.

Langen's apparatus, Fig 18, differs from those hitherto considered, in being placed above the furnace, which may therefore be kept filled to the throat in the same manner as one without any means of collecting gases. The charging portion is a conical ring, whose smallest diameter is equal to that of the throat, into which the charges are filled in the usual way. The gas tube is also slightly conical, diminishing upwards; the lower end, which is about 5 feet above the top of the column of materials in the shaft, is turned over into a gutter or water trough. The gases rising from the furnace are collected in a bell-shaped tube, whose lower end rests in the conical cup at the top of the furnace, while the upper part is turned over into a lip, which dips into the water trough on the gas tube, forming a perfectly air-tight stopper. At the time of charging, the bell, which is suspended by chains to a lever, is lifted, the upper end sliding on the outside of the gas tube, which forms a kind of telescopic joint. The charges in the cup then fall into the furnace. In order to keep the water joint tight, it is necessary to make good the waste caused by evaporation from time to time, owing to the high temperature of the gases. To prevent the chance of an explosion, a safety-valve is placed on the top of the gas tube at *a*, and another on the lateral tube at *b*.

Even in furnaces where the gases are not collected, the use of a conical charger is attended with considerable advantage. Where the diameter of the throat is large, it is customary to fix charging plates inclining inwards, immediately within the charging holes, which distribute the charges in a similar manner.

In the charcoal furnaces of Lake Superior and Styria, a charging barrow is used, which is constructed exactly in the same manner as the cup and cone. The body of the barrow is an inverted eight-sided pyramidal cup, the bottom being an upright cone, which, when dropped by a lever attached to its summit, leaves an annular space for the materials to pass out into the furnace, at the same time they are directed towards the circumference of the throat, in sliding over the surface of the cone. At Rhonitz, in Hungary, charging barrows are used having sliding cylindrical sides in addition to the dropping conical bottom, so that the charging takes place in a ring towards the sides of the furnace as well as at the centre.

Form of the Interior of the Blast Furnace. In laying out new works at the present time it is usual to build the furnaces of a more or less skittle or tub-shaped section, all sharply-contrasted slopes being avoided, the diameter increasing continuously from the throat to the boshes, and then being contracted in a similar manner down to the hearth bottom, without having a cylindrical hearth. The form of the body of such a furnace is well represented by a common soda-water bottle, supposing the neck and the pointed bottom to be removed. In Scotland the same kind of section is used, with the addition of a broad cylindrical hearth. In Cleveland slightly-curved stacks, with conical boshes and cylindrical hearths, are the rule. In South Wales the latter conditions are often reversed, the lower part, up to the top of the boshes, being made conical, while the stack, which is for a certain distance cylindrical, is terminated by a strongly-curved dome. In all cases of the above, however, the hearths are of considerable breadth.

In French, Belgian, and German furnaces curved sections are less common than in this country. A more especial characteristic is, however, the small diameter of hearth generally adopted, the sides being brought in from the boshes in a strongly-curved convex sweep. This type, which is usually combined with an extremely massive construction of hearth, is very similar in form to an inverted claret bottle, having the bottom and the greater part of the neck removed; the body, which increases from the bottom upwards with a slight taper, representing the stack, the shoulder the sweep of the boshes, and the narrow neck the hearth. Swedish charcoal furnaces are generally of considerable height when compared with their diameter; the hearth and boshes form part of the same cone, usually very acute. The stack is either wholly or in part cylindrical. In Styria the charcoal furnaces used for smelting spathic ores resemble those of Sweden by their considerable height, as compared with the breadth and the steep slope of the conical parts, but are specially distinguished by their extremely narrow throats, which in some instances do not exceed 2½ feet.

The height and other dimensions of blast furnaces vary very considerably in different localities with the nature of the ores and fuel. No special rules can be laid down as to the form best suited for a particular class of ore, experience having shown that the requirements of each class are to be met by special arrangements. The most useful guide in the construction of new furnaces is furnished by the condition of those that have been blown out after working upon the same kind of ore. It was by comparisons of this kind that the modern barrel-shaped furnace was elaborated by Gibbons, in South Staffordshire, from the older conical form, the section of the newer furnace being modified wherever the action of the fire was found to be strongest: thus square hearths were burnt out to a circular form, and the sharp angle at the joining of the hearth and boshes was also removed. It was therefore apparent that, by altering these parts in conformity with the indications, a double advantage was attained, a certain amount of materials being saved, while the furnace was sooner brought to its best working condition than was the case when it had first to be cut into shape by the heat.

If we consider the nature of the work done in the blast furnace with reference to the amount of iron produced in a given time, it will be evident that an increase of such production can only be obtained from the same ores by passing a larger number of charges through in the same time; this, however, depends upon the facilities possessed for withdrawing them by fusion at the bottom; for, however great the cubic contents may be, it is clear that new materials can only be supplied in proportion to the speed with which those charged before them are removed.

The power of fusion is, however, to be measured by the space offered for combustion of fuel by the blast, and as in the best condition of work, this space should be confined as much as possible to the plane of the twyers, it follows that increase of space for more active combustion is to be got mainly by augmenting the width of the hearth. The amount of such an increase is to be determined by the power of the blast, which must be of sufficient tension to penetrate to the centre of the hearth.

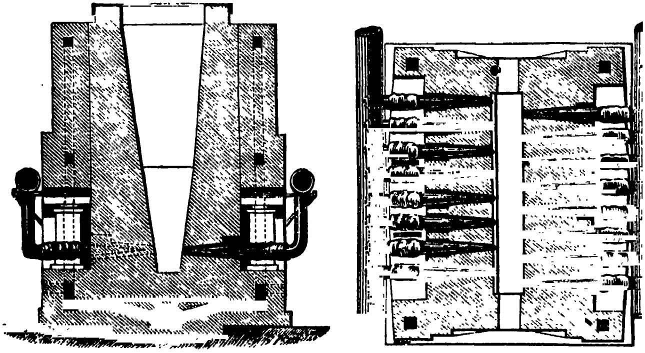
Greater height may be given to a furnace, either to increase its capacity, or to intercept more completely the enormous quantity of heat carried upward by the gaseous products of combustion. Strictly speaking, there should be no combustion of fuel, except in the region of fusion, and the space immediately adjoining, where the carbonic acid produced at the twyers is converted into carbonic oxide. The latter gas, and the nitrogen of the air consumed, are charged with the reduction of the oxides of iron in the ore to the metallic state, and the progressive heating of the materials in the upper region of the furnace. The greater the distance, therefore, of the upper end of the column of materials from the level of most active combustion, the more perfectly will the heat be abstracted from the gases; therefore, we might expect that the greatest economy of fuel would be found in the tallest furnaces, and this is practically the case, as exemplified in the newer furnaces in Cleveland, which have been successively increased from a height of 50 or 60 feet to 70 feet and upwards, in one instance attaining as much as 96 feet, with an increased saving of fuel in each case. Of course only the sensible heat is abstracted from the gases,—an amount that is quite independent of the further and much larger quantity that may be got by burning them in air.

The conditions limiting the height of the furnace are mainly due to the character of the ores and fuel, as regards their power of resisting crushing when exposed to the pressure of a tall column of materials, and the initial velocity of the blast. The favourable results given above, as obtained in Cleveland, are due to the extremely hard character of the coke employed, which, according to Bell, is capable of resisting a crushing strain of 5 cwt. per square inch. Very tall furnaces, therefore, can scarcely be used with tender fuel, such as soft charcoal, or coal, and pulverulent ores. Much of the anthracite of South Wales is in the same condition, as it decrepitates, and is apt to choke up the furnace, if not removed by an extra-powerful blast. The furnaces, therefore, worked with this fuel, though of large diameter, and provided with a great number of twyers, are usually of small height.

The time occupied in the descent of the materials from the throat to the hearth is chiefly dependent upon the capacity of the furnace. It is of the greatest importance that this should be so regulated as to insure an early commencement of the reduction of the ore to the metallic state at a low temperature, otherwise, in the event of protoxide of iron and silica coming in contact with each other in a more highly-heated atmosphere, a silicate is formed, which is easily fusible, but difficultly reducible, and, running down into the hearth, forms what is known as a scouring or black cinder, at the same time giving rise to white iron. The harder a furnace is driven, therefore, the greater is the tendency to deterioration in the quantity of the metal produced, owing to the quicker descent of the charges; and it will, therefore, be apparent that when an increased make is desired, larger furnaces should be used.

The difficulty of insuring uniformity of temperature in circular hearths of large character has led to the proposal of a more elongated form, such as an ellipse or oblong rectangle; the latter being adopted in Rachette's furnace, which was introduced in Russia a few years back, and has been tried experimentally in other parts of Europe. It is represented in plan and section in Figs. 19 and 20.

The oblong hearth is combined with a shaft, increasing regularly in diameter upwards, the section at the throat being from two and a half to three and a half times as large as that measured at the level of the twyers. The object of this arrangement, which gives a furnace similar in form to a calcining kiln, is to produce a more prolonged contact between the gases and the materials of the charge, by reducing the velocity of the upward current.



Rachette's blast furnace.

Fig. 19.—Vertical section. Fig. 20.—Plan at twyer level.

The use of drying flues is another new feature in Rachette's furnace; these are a series of ramifying rectangular passages, traversing the outer casing of the stack at different levels, which are in connection with a similar chamber placed below the hearth. Before blowing in, a fire, placed in the chamber, warms up the whole of the masonry uniformly, and more quickly than can be done on the old system; afterwards the flues may be used for the reverse purpose of cooling the masonry by the circulation of cold air. The twyers, from twelve to sixteen in number, are arranged in two rows, breaking joint with each other, on the opposite long sides of the hearth; a dam and tapping place are provided on each of the short sides, so that the removal of slag and iron may be effected from either end.

In order to obtain greater regularity in the distribution of the blast, the large number of twyers may be replaced by a single mouth-piece, with a long, narrow, rectangular aperture, which delivers the air in a thin stream uniformly along the entire length of the hearth. This system of twyer, together with the elliptical form of hearth, has been adopted in the construction of cupolas for smelting slags in the Lake Superior copper works. In the original furnaces of this class in the Ural, the breadth of the hearth at the twyers is 3 feet, at the throat 7 feet, height 30 feet, cubic capacity 1,950 feet, and the daily production, when working on rich magnetic ore (67 per cent.), with charcoal and cold blast, about 30 tons of grey pig iron.

The mode of charging has an important influence upon the working of blast furnaces: this becomes evident when we consider that, in order to obtain regularity of action, the descending materials ought to be heated uniformly by the upward current of hot gases. This, however, is by no means the case, owing to the essential differences in the character of the two motions, the gases following the sides of the furnace close to the wall, the flow at the centre being almost imperceptible.

Thus, in an open-topped furnace, a wooden pole may be plunged into the centre of the charge to a depth of 2 or 3 yards, without being carbonised, while the materials adjoining the wall, at the same level, are at a red heat. The descent of the charges, however, takes place under precisely opposite conditions, the velocity being greater at the centre than at the sides, where the fragments are retarded by friction against the wall. It therefore appears that the central portion of the column of materials is likely to be imperfectly heated in its passage downward, and to arrive in the region of fusion in an unprepared state.

When the charges are of ore and fuel, deposited uniformly in the throat of the furnace in parallel layers, the increased velocity of descent at the centre causes the middle of an upper layer to overtake the sides of that preceding it, so that at a certain depth below the mouth the contents of the furnace are more or less completely mixed. But for this circumstance, it would be impossible to maintain a uniform heat in the hearth, which would become alternately hot and cold, according to whether fuel or burden happened to be in front of the twyers.

In large furnaces, where it is necessary to drop the charges from a certain height into the throat, the distribution of the materials becomes complicated by the nature of the upper surface of the column in the shaft, which may be either a cone raised in the centre, an inverted or conical funnel depressed in the middle, or a combination of both, such as a conical ring, according to the method of charging employed. The charges, therefore, instead of being deposited in parallel layers, have to accommodate themselves to the inclined surface of the preceding one.

In the simplest of the above cases the charge is dropped into the centre of the throat, and forms a conical heap, sloping outwards to the circumference at an angle varying, with the nature of the materials, from about 35° to 40°, the latter being the maximum inclination of the talus formed by coke. Owing to differences of form and density, the fragments of ore and fuel take up different positions in the furnace, the former usually remaining in the place where they first strike the surface of the column, while the lighter and more voluminous masses of fuel roll down the slope until they have established a talus at the proper angle of repose. It will easily be seen, therefore, that this is the worst possible combination, the fuel being mainly distributed towards the circumference, where there is a comparatively free passage for the gases, while the ore remains in a dense column, impenetrable at the centre, and descends without being properly heated. When coke is used, the friction of the fragments against the wall is so great as to increase the tendency to form obstructions, or *scaffolds*, and their attendant evil, known as slips, when the charge falls, owing to the removal of the obstruction, by gradually increasing pressure from above, and the removal of supports below. The ore in the centre, by its greater velocity of descent, passes through the fuel charged before it, producing an inversion of charge, so that the slags change irregularly from white to black, according to the preponderance of ore or fuel at the twyers.

When the charges are thrown in close to the circumference of the throat, the surface of the column of materials forms a conical cup, the lighter fragments rolling inwards towards the centre, while the ore remains at the outside. The tendency is, therefore, for the fuel and larger masses of ore to collect in the middle, where it forms a column, which, on account of its ready permeability as compared with the more densely-packed ore at the sides, gives a more equable draught over the entire horizontal section of the shaft, at the same time that the bulk of the ore descends slowly through the region of maximum heating by the gases, both conditions tending to uniformity of working and economy of fuel. When the throat is very wide, however, and the furnace low, the draught at the centre may become too strong, leading to an unnecessary consumption of fuel by diverting the gases from the sides. The continual contact of metallic oxides has also an injurious effect upon the lining of the furnace, as the silica of the bricks is liable to combine with protoxide of iron, forming a fusible silicate, by which they are rapidly destroyed.

When a conical funnel or charging plates are used, the surface of the column in the furnace presents an annular ridge, sloping both towards the centre and the circumference, the ores occupying the crest of the ring, while the fuel and larger blocks are intermixed at either side. This is by far the most favourable condition for uniform working, as the charge and fuel are more perfectly mixed than by either of the preceding methods. The use of the movable cones below the funnel, as in the ordinary cup-and-cone arrangements, corrects the tendency to accumulations at the centre, which is experienced when the charging funnel is too much contracted at its lower end.

In Sweden, charcoal furnaces with narrow throats are charged by hand, the richer magnetic ores broken into small pieces are placed in a ring close to the wall, while the more siliceous hematites and specular ores, as well as the limestone flux, are spread uniformly over the surface. The charges are weighed in a large wrought-iron scoop with a long wooden handle, which is suspended by a chain above the top of the furnace.

Tapping. The molten metal accumulating in the hearth of the furnace is removed at regular intervals by tapping, or piercing a hole through the lower part of the dam, and allowing the metal to flow into sand or cast-iron moulds placed in front of the furnace. Before tapping, the blast is shut off, and the tymp stopping removed. The tap-hole is opened by driving in the point of a wrought-iron bar, which is held by one man, while another strikes the end with a sledge hammer if necessary. The moulds, or pig beds, usually consist of a series of furrows in the sand of the casting floor, moulded by wooden cores of a D-shaped section. The curved side is placed downwards, and usually has the name or mark (brand) of the works attached to it. The moulds are arranged in parallel series on either side of a central feeder, known as a sow; and as soon as one series is filled, the current is allowed to flow into the next, and so on until the cast is completed. In Sweden cast-iron moulds are generally used instead of sand.

When the ores contain lead, a certain quantity may be obtained in the metallic state by tapping the hearth at the lowest possible point, or by making a hole below the hearth bottom, and collecting the metal which finds its way through the joints of the stones. In the latter case a small fire is kept burning in the hole to prevent the lead from solidifying, and it is then allowed to accumulate until a sufficient quantity has been obtained for a cast.

Blowing in. When a furnace is quite new, the whole of the masonry must be very carefully dried before it can be lighted. This may require several weeks, according to the state of the atmosphere and the nature of the materials employed. When perfectly dry the hearth is filled with wood, and the upper part of the furnace, to the top of the boshes, with coke, which is then lighted from below. As soon as the fire has burnt through to the surface a light charge of ore is given, which is repeated when the fire reappears at the top.

Twelve hours after lighting, a grating of bars, carried by an external bearer laid across the rack plates of the hearth, is placed within the furnace, a little below the level of the tymp; the column of materials being thus supported, the cinders and ashes of the coke filling the hearth are then removed, and the air passing through the grate bars, revives the combustion in the upper part of the furnace. When the lower part of the mass is glowing, the bars are withdrawn, and the ignited materials are allowed to fall into the hearth. The fire is then slackened by stopping up the fore-hearth as before. The same process is repeated at the end of every twelve hours, or if it is desired to get the furnace in blast quicker, every six hours.

As soon as the first charge gets down to the hearth the dam and twyers are fixed in position, and the blast is turned on, cold air, and nozzles of a reduced diameter, being adopted at first. The furnace is then filled to the throat, as if in regular work; but the weight of the charges, as well as the temperature of blast and diameter of twyers, must be gradually increased, so as to get to the proper burden in about seven or eight days.

When several kinds of ore are at hand it is well to commence with the poorest, as for the same volume of charge the burden will be lighter.

The above is the old method of scaffolding, which is still used in France. In England a more rapid plan is adopted. The top of the wood in the hearth is covered by a considerable quantity of coke, followed by alternate layers of coke and limestone, the latter for fluxing the ash of the fuel, until the furnace is one-third full. When the fire is well started, small charges of ore are added, and the blowing is commenced with twyers of a reduced area. If properly managed, grey iron and clean cinders may be obtained from the beginning; but for this purpose it is essential not to increase the burden too rapidly, or to drive too hard at first.

Blowing out. When a furnace is to be put out of blast, it is advisable to reduce the charges as much as possible for a short time before, in order to get the hearth as hot as possible, so as to remove any metallic obstructions. The gas tubes, and all metal fittings of the throat, are then removed, and the charging being stopped, the contents of the furnace are entirely liquefied by the last charge of fuel. The last tapping must be made from as low a point as possible.

The sides and bottom of the hearth are often found to be covered with masses of imperfectly-agglomerated malleable iron, the so-called bears, wolves, or sows, and isolated crystals, or even large masses of a copper-red compound, formerly supposed to be metallic titanium, but which has been shown by Wöhler to be a cyano-nitride having the composition $Ti\,C^2N + 3\,Ti^3N$.

Stoppage of Furnace. It may sometimes happen, through failure of the blast engine, or a deficiency of materials, that a furnace must be stopped for some time. This is done by closing up the throat and all the twyer holes hermetically with sand or clay. If the charges have been previously diminished to a certain extent, so as to keep a good body of fuel in the furnace, it may be stopped for about a week without serious inconvenience; but if the blast be interrupted for a longer period, the cooling takes place to such an extent that the furnace becomes blocked up, and would probably be obliged to be abandoned.

CHAPTER IX.

CAPACITY AND PRODUCTION OF BLAST FURNACES.

The greatly-increased production of modern, as compared with older furnaces, is due partly to their much larger size, and partly to more rapid driving, produced by giving more blast. No general rule can be laid down as to the time necessary for complete reduction of the ores previous to their actual fusion and the separation of metal and slag by liquation, as it is obviously dependent upon many variable elements, such as the greater or less density of the ores and fuel, the richness of the former, whether they are readily reducible, or have a tendency to scorification, &c. This point must, therefore, be determined by actual experiment for each particular furnace, by varying the amount of blast and the burden of ore and fluxes, until the particular result required, either in respect to quality or quantity of produce, is obtained. Other things being equal, the time of reduction will be lessened the more perfectly the materials are exposed to the action of the upward gaseous current. It therefore becomes of the greatest importance to render the flow of gases as uniform as possible throughout the mass, by the use of proper charging and gas-collecting appliances. Especial care must be taken that no hindrance is offered to the free efflux of the current at the top of the furnace. For this reason, these methods, based upon the collection of the gases above, or in the centre of the charge, are to be preferred to such as employ lateral flues, penetrating the wall below the level of the throat, whereby the current is diverted, without being allowed to give up its heat to the upper part of the column of materials above the flues.

An increase in the volume of blast, keeping the pressure constant, has a tendency to put the furnace on white iron. By increasing both pressure and temperature, on the other hand, especially with refractory ores, greyer or more highly-carburised iron is likely to be produced.

In the table on page 199 the cubic contents and daily make of a series of furnaces are shown, together with the effective volumes required to produce one ton daily in each case.

The quantities in the last column but one cannot be fairly paralleled with each other, without taking into account the differences in the nature of the materials employed. Thus, in Nos. 1, 2, and 4, the ores are treated almost without fluxes, so that the production of slag is reduced to a minimum, whereas in the largest English and Welsh furnaces, working with a mixed burden, the weight of slag considerably exceeds that of the iron made. The descent of the charge is quickest in the Styrian furnaces, where rich and easily-reducible spathic ores pass through the furnace in four and a half or five hours. In Wales, on the other hand, in some instances, the charges do not arrive in the hearth until forty-two hours after the time of charging. In Cleveland the time of descent is about thirty-six hours; while,

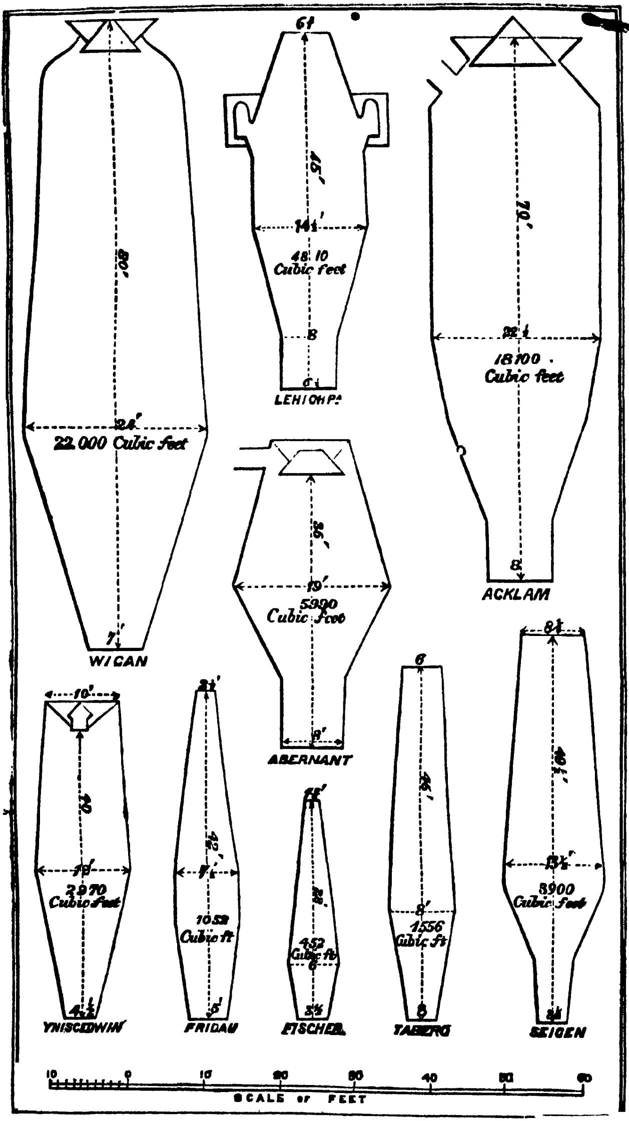


Fig. 21.—Comparative sections of blast furnaces

No.	Name.	Fuel.	Blast.	Ores.	Cubic contents, feet.	Daily make, tons.	Effective volume in feet per ton made.	Class of iron.
1	*Fischer, Styria	charcoal	cold	spathic	452	7½	60·2	white forge
2	*Fridau, ,,	ditto	hot	ditto	1,052	20	52·6	ditto
3	Säfvenäs, Lapland (Fig. 4)	ditto	ditto	magnetic	1,090	8	136	grey
4	Langshytta, Dalarne	ditto	ditto	ditto	2,316	20½	110	ditto
5	Rhonitz, Hungary	ditto	ditto	spathic, argillaceous, and cinders	2,600	10	260	mottled forge
6	*Yniscedwin, South Wales	anthracite	ditto	argillaceous	2,970	12	248	grey forge
7	*Heinrichshütte, Siegen	coke	ditto	spathic and red	3,900	26	150	grey and spiegeleisen
8	*Lehigh, Pennsylvania	anthracite	ditto	—	4,810	35	138	—
9	Staffordshire, average	coke	ditto	—	4,600	20	230	grey forge
10	Blaenafon, South Wales	ditto	cold	—	5,540	15	370	grey
11	*Abernant	coal	hot	—	5,990	48	107	white
12	Scotch, average	ditto	ditto	—	7,000	26	—	grey foundry
13	Tees-side, Cleveland	coke	ditto	Cleveland	7,060	30	235	grey
14	Dowlais, South Wales	coal	ditto	argillac., &c.	8,650	50	175	ditto
15	*Barrow, Lancashire (Fig. 6)	coke	ditto	red	9,300	60 to 90	103	ditto
16	*Acklam, Cleveland	ditto	ditto	Cleveland	18,100	50	362	ditto

The sections of the furnaces marked * are given in Fig. 21.

in the older blackband furnaces in Scotland, it varies from two and a half to three and a half days.

The nature of the work done by blast furnaces can only be understood by examining the conditions of production prevailing in different districts. The following examples give the working details of a few examples selected as types from various localities:—

At Eisenerz, in Styria, the furnaces consist of two truncated cones, with a very narrow throat, and are distinguished from the ordinary blast furnace by being without a fore-hearth, the metal and slag being allowed to collect in the hearth, which is comparatively shallow, and are tapped off together at short intervals, the number of casts varying from 5 to 16 in twenty-four hours. The ores are chiefly spathic, poor in manganese, partly pure, and partly altered into brown hematite. In order to get rid as completely as possible of the sulphur due to the presence of pyrites in small quantities, they are allowed to weather for two, three, or more years after roasting. The amount of iron varies from 35 to 55 per cent. The object sought to be attained is the production of white iron, for conversion into bar iron, from rich and easily-reducible ores, with a minimum expenditure of fuel (charcoal). This is done by working under a very heavy burden, the tendency to obstructions caused by this proceeding being counteracted by giving charges of fuel alone at regular intervals. Some varieties of ore are of the self-fluxing kind; but as a rule they contain a considerable quantity of lime, requiring the addition of siliceous and aluminous fluxes, such as clay or clay slate. The following are the charges and yields of the two furnaces whose sections are given in Fig. 21:—

1. *Von Fridau's Furnace, Vordernberg.* The charge consists of 5 to 6 cwt. of roasted ore, 10 per cent. of clay, and 8 to 10 lbs. of washed metal, *i.e.* granulated pig iron, recovered from the slag by stamping and washing. The fuel is measured; 2 tubs, or 15½ feet, or about 101 lbs. of soft pine-wood charcoal being employed per charge. The burden of ore is gradually raised from 3 to 6 cwt. per charge, and then diminished similarly, a blank charge of fuel being given at each change. The daily production is from 18½ to 20 tons. The twyers plunge or incline at an angle of 5°, so that the furnace fulfils, to some extent, the functions of a refinery.

2. *Von Fischer's Furnace, Vordernberg.* This is one of the smallest furnaces in the world. (See section, Fig. 21). The usual charge includes 223 lbs. ore, 15 lbs. clay, and 4 lbs. of washed metal, to 1¾ tub (13⅔ cubic feet or 95 lbs.) of charcoal. The daily production is 7½ tons; the furnace is tapped at intervals of one and a half hours, fourteen charges being made during the same period, including a blank one, *i.e.* of fuel without burden.

These furnaces are driven at a very high speed. The first tapping takes place twelve hours after lighting, and afterwards at intervals of two to two and a half hours. The burden of ores smelted per tub of 7¾ feet of charcoal varies from 170 to 220 lbs. with cold, and from 220 to 250 lbs. with hot blast. The consumption of charcoal is from 65 to 70 per cent. of the weight of the metal produced, or from 13⅓ to 14 cwt. per ton.

The ores are well adapted for the production of spiegeleisen, though they contain less manganese than those of a similar kind smelted in Siegen; but owing

In the Siegen district the ores smelted are principally spathic and brown hematite, with a considerable quantity of manganese, together with red schistose hematite, partly raised in the neighbourhood, and partly brought from Nassau. The products are white and grey pig metal and spiegeleisen, all of which are employed in steel-making; the first (*weissstrahlig* or *rohstahleisen*) in the open fire or puddling furnace, and the others in the Bessemer process. Formerly the furnaces were small, and chiefly worked with charcoal, but in those of newer construction the use of coke and hot blast is found to be attended with greater regularity in the composition and quantity of the products. The following examples give the working details of two of the largest and most improved furnaces :—

Heinrichshütte. The ordinary charge contains, by measure :—

⅝ roasted spathic ores . .	7 cwt.
⅜ brown hematite . . .	4 ,,
25 to 30 per cent. limestone .	3 ,,

The fuel is coke from the Ruhr coal-field, containing from 9 to 10 per cent. of ash. Each charge weighs 14 cwt., and contains from 44 to 48 per cent., corresponding to a burden of 36 cwt. of ore and flux per ton of metal. The daily number of charges is from 38 to 40.

The blast is supplied through three twyers, that at the back being 2½, and those at the sides $2\frac{13}{16}$ inches diameter. The pressure is 3⅛ lbs. per square inch, and the temperature from 270° to 300°. About 26 tons of a white lamellar metal (*rohstahleisen*), suitable for conversion into steel, and sheet and wire iron, are produced daily, with a consumption of from 20 to 22 cwt. of coke per ton.

At Charlottenhütte the charges for spiegeleisen are of the following composition:—

	cwt.	
Roasted spathic ores . .	28·8	yielding from 44 to 45 per cent.
Raw brown hematite . .	7·2	
,, limestone . . .	9·0	
Total charge . . .	45·0	
Coke	20·0	containing 8 per cent. of ash.

Daily number of charges, 36; produce, 30 tons; consumption of coke per ton, 22 to 23 cwt.; number of twyers, 3; back, 3 inches; sides, 3⅜ inches diameter; pressure of blast, 3⅜ lbs. per square inch; temperature, 280° to 300°. When working on white forge pig, the charge is increased by the addition of Nassau red hematite to 50 cwt., and the produce to 35 tons.

The production of spiegeleisen is facilitated by the prevalence of a high temperature in the region of the hearth, the use of hotter blast being found to increase the quantity of manganese reduced. The metal produced under the conditions given above contained 8 per cent. of manganese, which was reduced to 4 per cent. when the temperature of the blast was allowed to fall to 100°.

The slag must be as nearly as possible neutral, *i.e* having the oxygen of the bases equal in amount to that of the silica; but as the silicates of lime and alumina of this form are extremely refractory, the requisite fusibility is attained by the partial substitution of other bases, such as magnesia, but more particularly protoxide of manganese. Silicate of protoxide of manganese, requiring a very high temperature for its reduction by carbon, does not exercise a decarburising influence on molten cast iron to the same extent as the corresponding silicate of protoxide of iron.

Owing to their basic character, the slags have a tendency to corrode the sandstone hearth of the furnace very rapidly. This is counteracted, to a certain extent, by the use of water blocks surrounding the exterior of the hearth at several different levels.

The amount of manganese reduced also depends upon the state of oxidation in which it exists in the ores, being greatest when spathic ore is used, and least when supplied in the form of manganesiferous hematite. Formerly the spiegeleisen of Müsen was produced by the treatment of the Stahlberg spathic ore without flux; but since the introduction of limestone into the charge, the metal is much richer in manganese.

The furnaces used in Sweden are in many respects similar to the Blauofen of Styria, the fore-hearth being small and narrow. Their dimensions are usually small, varying from 600 to 2,300 cubic feet. The largest, at Sandviken, near Gefle, is 52 feet high, 9½ feet wide at the boshes, and 6 feet at the throat, with six twyers, four of which are used at one time; the other two are in the tymp, South Wales fashion. The slags and metal are drawn on opposite sides of the hearth, an arrangement similar to that of the furnace at Säfvenäs, Fig. 4, so that the iron may be run directly into the

Bessemer converters. The clay and quartz lining of the hearth is from 6 to 8 inches thick; it consists of from 4 to 6 parts of quartz, mixed with 1 of fire-clay.

The Swedish ores vary considerably in character. The best are those known as self-fluxing,—*i.e.*, containing earthy materials in the proper proportions to form a fusible bisilicate slag without further addition. The ores of Dannemora, Langbanshytta, and Langshytta are of this character: they contain from 50 to 59 per cent. of iron. At the last-named furnaces, the charge, with the addition of from 3 to 5 per cent. of limestone, or blast-furnace slag, contains at times as much as 60½ per cent. of iron. As a general rule, the more quartzose hematites and micaceous ores are mixed with calcareous magnetites, and fluxed with dolomitic limestone, the average percentage of the charges being from 35 to 52 per cent. The maximum amount of flux, 25 per cent. of limestone, is used in smelting the siliceous itabirite of Nora; and at Taberg, where the ore is a serpentine impregnated with magnetite, and the charge contains only 20 per cent. of iron.

The temperature of the blast does not exceed 200°, the pressure varying from 10 to 15 lines of mercury, or at most 20, in the newer furnaces. The gases for heating the blast are drawn through an opening in the side of the furnace, about 12 or 14 feet below the throat; the stoves are of the horizontal, serpentine, or Wasseralfingen pattern, with pipes of circular section; the coil rarely containing more than three or four turns. Cold blast is only used at Finspong, in the manufactory of gun-foundry iron; even the Dannemora furnaces are now worked with blast heated to 80° or 100°

The average weekly production of the Swedish furnaces ranges from 700 to 1,400 centners (24 centners = 1 ton). In excess of these yields are those of Langshytta, 2,800 ctr.; Sandviken, 2,500 ctr.; and Langbanshytta, 1,800 ctr. At Taberg, on the other hand, the amount is as low as 600 ctr. The furnaces are, as a rule, only kept in blast during the winter months, in 1864 the average was 150 days, when the ores and fuel can be easily brought to the works by means of sledges. At the mouths of the Lapland rivers, some of the furnaces are in connection with saw-mills, the blast-engine boilers being fed with the waste slabs and sawdust; the ores and fluxes, in such cases, being brought from the south in the summer time by sailing vessels.

The consumption of charcoal varies with the nature of the ore, the average for the whole country being from 16 to 17 cwt. per ton of white or mottled forge pig, and about one-third more, or from 21 to 22 cwt. per ton, of grey metal, suitable for foundry or Bessemer steel purposes. At Langshytta, the consumption is as low as 13½ to 14 cwt., making white and mottled iron. The poor ores of Taberg require as much as 50 or 60 cwt. per ton.

The charcoal furnaces of Lake Superior are noticeable for their large productions. At Greenwood furnace, near Marquette, two classes of ore are smelted—namely, brown hematite, containing an average 40 per cent., and slaty red hematite, or specular schist, with 60 per cent.; the former, although poorer, is preferred, as being more easily reducible than the harder slaty ore. The two qualities are mixed to yield 55 per cent. of pig iron. The furnace is 40 feet high, 11 feet diameter at the boshes, and 4 feet at the throat; the gases are collected in a narrow ring flue, enclosed by an iron cylinder, remaining open. The blast, at a temperature of 330° and a pressure of 1½ to 2 lbs. per square inch, is introduced through two twyers of 3½ inches in diameter on opposite sides of the hearth. A variegated crystalline limestone is used as flux, to the amount of about 10 per cent. of the weight of the ore. The fuel is hard wood, principally maple charcoal, the consumption being at the rate of 125 bushels, weighing from 16 to 20 lbs. each, or about 25 cwt. per ton of pig iron. The ores are not roasted, but all the materials are reduced to the size of ordinary road metal by a Blake's rock breaker previously to charging. The daily produce in July, 1865, before the furnace had arrived at its full make, was from 16 to 18 tons, mostly small-grained, dark grey pig, suited for Bessemer steel-making and foundry work, especially chill casting, such as railway wheels. At Wyandotte Iron Works, near Detroit, in a furnace of similar dimensions, the consumption of light-wood coals is 140 bushels of 14 lbs. weight each per ton. The charges are 500 lbs. of red slaty ore, 40 lbs. of limestone, from the Niagara formation, which is supplied in the form of rolled pebbles, and 40 lbs. of forge cinders; the average yield being 65 per cent.

The large amount of fuel required by these furnaces has already made a very decided impression on the surrounding timber. The average yield per acre of the best timber land on Lake Superior is often 50 to 60 cords of 128 cubic feet measurement, or about 2,700 bushels; a quantity only sufficient to make 20 tons of pig iron. So that the daily supply of a single furnace necessitates the clearing of an acre of forest; or, supposing it to be put down in the centre of a uniformly-wooded district, and to make 16 tons daily, two years' working would be sufficient to clear a circle of a mile in diameter. It is evident, therefore, that even in a densely-wooded country a permanent supply of fuel cannot be looked for except where the works are placed within reach of rivers or navigable waters.

In South Staffordshire the make is chiefly grey pig for forge purposes, which is afterwards converted into bars, plats, and other small varieties of merchant iron. The ores employed are partly "native mine," *i.e.* clay ironstones from the coal measures, and partly brown and red hematites from North Staffordshire, Lancashire, and other parts. Forge cinders are extensively used in the production of common hot blast metal, but the best mine pigs are still made with cold blast and coke. According to Jones the annual consumption of this district is as follows:—

	Tons.
Native mine (clay ironstones of the coal measures)	948,500
Brown hematite, "hydrate," or Froghall calcareous brown hematite	368,000
Red hematite, Ulverstone	50,000
Northamptonshire brown iron ores	200,000
North Staffordshire argillaceous carbonate and blackband	180,000
Forge and mill cinders	150,000
	1,896,500

The coals of South Staffordshire are of a non-caking class, yielding only a slightly coherent coke, from the absence of binding qualities; therefore the slack cannot be coked alone. Of the two principal seams used for iron-making, the thick yields 54 per cent. by weight of coke, with 0·31 of sulphur and 4·18 of ash; the lower, or heathen coal, contains 0·51 of sulphur and 4·58 of ash. Generally the fuel is used partly raw and partly coked. The pressure of blast varies between 2½ to 3 lbs. per square inch, and the temperature from 300° to 330°, except in the small number of cold blast furnaces.

The flux used is principally Silurian limestone from Dudley and Wenlock Edge, and carboniferous limestone from North Staffordshire and Derbyshire.

The average consumption of coal per ton of metal made is for hot blast furnaces from 55 to 60 cwt., and for cold blast from 60 to 70 cwt., or rather, the corresponding equivalent in coke, besides 2 cwt. of small for calcining, and 15 to 22 cwt. used in the hot blast stoves and steam boilers, very few furnaces in this district being provided with gas-saving apparatus.

The average weight of the charge per ton of pig iron is—

48 cwt.	Coal-measure ores.
7 ,,	Red hematite.
14 ,,	Limestone.

The average yield of 119 furnaces in blast in 1866 is stated to have been between 120 and 150 tons each per week; the largest make from 180 to 250 tons weekly; but there are only a small number in this class.

The produce is classified into six numbers as follows:—

Nos. 1, 2.	Grey foundry pig.
,, 3, 4.	Grey forge pig.
,, 5, 6.	Mottled and white forged pig.

According to quality and materials employed, the following scale is adopted in South Staffordshire:—

Common forge pigs.
,, foundry pigs.
Best foundry pigs.
Mine pigs, smelted from ores without cinders.
Best mine pigs, special brands.
Hydrates, made from Froghall brown hematite.
Cold blast pigs.

The general conditions of working in the blast furnaces of South Wales are in many respects similar to those of South Staffordshire, especially as regards the ores which are partly raised on the spot, and partly brought from other districts, often at a considerable distance. The staple product is white forge pig, which is in great part used in the manufacture of rails in the local forges. The higher qualities of metal are taken by the tin-plate works, and a few furnaces make cold blast pig for founders' use. The following are the principal varieties of ores:—

1. Native mine, chiefly argillaceous carbonates, with some blackband.
2. Brown hematites from Llantrissant, Forest of Dean, Cornwall, and Northamptonshire.
3. Red hematite from Cumberland.
4. Spathic ore from Somersetshire.

Brown hematite from Spain, and the well-known specular ore of Elba, are also used to a small extent, being brought back by colliers returning in ballast. In the eastern or bituminous coal district, the fuel is partly raw coal and partly coke, except in the case of cold blast furnaces, where the latter is exclusively used. Further westward, in the neighbourhood of Swansea, a small number of furnaces are worked with anthracite. The impurities in some of the principal varieties are as follow:—

	Sulphur.	Ash.
Anthracite . . .	0·7 per cent.	9·14 per cent.
Coke, Blaenafon . .	0·74 ,,	5·35 ,,
,, Pontypool . .	0·76 ,,	12·15 ,,

Forge and mill cinders are largely used in the production of white iron for rails. The following are a few of the principal varieties of charges and consumption of materials per ton of metal produced :—

Cold blast pigs.	Blaenafon.	Pontypool.
Argillaceous ores (raw) .	72¼ cwt. (calcined)	46⅔ cwt.
Forest of Dean hematite .	—	9 „
Limestone . . .	20 „	24 „
Coke	54½ „	50½ „

The average weekly make at Blaenafon is 104½ tons. The fuel consumed corresponds to between 3 and 4 tons of coal per ton of iron.

Truran gives the following details of charges employed at Dowlais for different makes of pig iron per ton: they refer to a period several years back :—

Quality of metal.	Foundry.	White Forge.	Common Forge.
Calcined mine . . .	48 cwt.	28 cwt.	—
Red hematite . . .	— „	10 „	16 cwt.
Forge and refinery cinders .	— „	10 „	25 „
Limestone	17 „	14 „	16 „
Coal	50 „	42 „	36 „
Weekly make . . .	130 tons	170 tons	190 tons

The capacity of the furnace is about 8,500 cubic feet: the blast is supplied at a pressure of 3 lbs. per square inch. The estimated time of descent of the charges is from forty to forty-six hours.

In 1863, at the same works, the consumption of coal per ton of mine pig made from mixtures in variable proportions of argillaceous ore, red and brown hematite, was reduced to between 24 and 29 cwt., the make of the furnace ranging from 174 to 280 tons, in round numbers, per week. The larger yield, corresponding to the smaller consumption of fuel, was due to the increased richness of the charge from the preponderance of red ore. In the newer large furnaces producing white iron the make is often considerably higher, and ranges from 250 to 300 tons weekly. They are mostly of large capacity, but vary very considerably in outline. A common form is that having a cylindrical body and domed top. The use of the cup-and-cone charger, and the economising of the waste gas for steam and hot blast purposes, is also very general.

In the anthracite district the furnaces are of comparatively small volume and height, though the newer ones show a tendency to increase in the latter direction. As has already been mentioned, the use of tall furnaces is attended with difficulty, owing to the decrepitation of the fuel, which gives rise to a closely-packed column of materials, only penetrable by a very dense blast. Probably Rachette's pattern of furnace might be applied with advantage in smelting with anthracite. The average consumption of fuel is about 44 cwt. per ton of pig iron, but in one instance at Yniscedwin it has recently been brought down to as low as 18 cwt.

The total number of furnaces in blast in South Wales in 1865 was 118; the average weekly make of each was 133 tons, not including 9 anthracite furnaces, averaging 62 tons each.

The Cleveland district is remarkable for the large size and height of its furnaces, which are entirely worked with hard coke from the south of Durham, containing on an average from 0·6 to 0·8 per cent. of sulphur, and from 4½ to 8 per cent. of ash. The ore is principally the green argillaceous carbonate named after the district, whose composition has already been given at p. 78. In some instances red hematite is used as a mixing ore, but to a very slight extent. In the raw state the Cleveland ore contains from 29 to 32 per cent. of iron, which is increased to 40 per cent. on calcination. The following figures were given by Beckton as the average composition of charges in 1864 per ton of pig iron:—

70	cwt.	Cleveland stone.
15	„	limestone.
26	„	coke.
10	„	coal for calcining, heating blast and boilers.

According to J. L. Bell the pressure of blast used in 1863 was from 3 to 4 lbs., and the temperature 300° to 350°: the average weekly make varied from 200 to 220 tons. At Consett it is from 420 to 450 tons, and one furnace at Norton has made 550 tons. At Ormesby 45 tons have been got at a single cast.

The size of the Cleveland blast furnaces has increased very rapidly in the last two or three years. In 1863 the average height was from 42 to 55 feet, and the width of the boshes from 14 to 18 feet; but these dimensions are in the newest furnaces increased to between 70 and 102 feet high, with a maximum width of 27 feet. The Acklam furnaces at Middlesborough, which are 70 feet high, 8 feet in diameter at the hearth, and 22½ feet at the boshes, with the upper part of the body cylindrical, are each capable of holding 1,250 tons of materials, and make 350 tons of pig iron weekly. In all cases a notable saving of fuel has been experienced by increasing the height of the furnace, the upper part of the column of materials absorbing the excessive heat of the waste gases. The latter are afterwards used for raising and heating the blast, but have not as yet been applied to roasting the ores.

The average size of Scotch furnaces is stated at 16 feet* in diameter and 55 feet in height, and their production from 230 to 270 tons weekly. These figures probably refer to the blackband districts, as in 1865 the average of 141 furnaces in the whole of Scotland did not exceed 159 tons per week.

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* See note on the progressive increase of the Cleveland furnaces,

The largest furnaces, considered in regard to production, are those of the hematite districts of Lancashire and Cumberland. The total number in blast in 1865 was 13, with an average make of 315 tons each per week. At Barrow-in-Furness, the furnaces (whose section is given in Fig. 6, p. 142) are 56 feet high, 7 feet wide at the hearth bottom, 16½ feet at the boshes, and 17½ feet at the throat. The volume is 9,500 cubic feet. According to Jordan, in 1864, the following materials were required to make a ton of pig iron:—

Red hematite (unroasted) . .	34—34½	cwt.
Coke from Durham . . .	18—18½	,,
Limestone	5¾	,,
Coal slack for stoves . .	3	,,

The gases are partially drawn off by a central tube and exhausting fans, as described at p. 180, and are exclusively employed in firing boilers. The blast is supplied at a pressure of 2½ lbs. per square inch, and a temperature of 350°, through six 3-inch twyers, the volume delivered per minute being about 7,000 cubic feet. The maximum production under these conditions appears to be about 90 tons per day. Ordinarily, about 20 tons are obtained at each cast, which takes place at intervals of six hours, giving a total amount of 80 tons daily. The iron made is converted on the spot into Bessemer steel.

At Kirkless Hall, near Wigan, the same ores are smelted under generally similar conditions to those last mentioned. A pair of new furnaces recently erected, but not yet lighted, are 80 feet high and 20 feet in diameter, with closed tops and cup-and-cone chargers; their capacity is 22,000 cubic feet, or about two and a half times as great as the Barrow furnaces. In Cumberland the addition of a proportion of the aluminous ore of Belfast to the charge is found to have an advantageous effect.

In Belgium the ores smelted are chiefly red and brown hematite. The former, a mixture of specular and micaceous ore, is known as *violet mine;* the latter, or *yellow mine,* is mostly ochreous and earthy, requiring to be subjected to the processes of crushing and dressing before it is fit for treatment in the furnace. A variety of spathic ore, containing a considerable proportion of carbonate of zinc, found at Angleur, near Liege, has the reputation of making an extremely strong iron. A large proportion of the brown hematite is obtained from the oolitic formations in Luxemburg. In 1864 the number of furnaces in blast and the total production were as follow:—

46 coke furnaces produced .	444,430 tons.
6 charcoal furnaces produced .	5,545 ,,

corresponding to a weekly make of 186 tons per furnace on coke, and 18 tons on charcoal: the latter figure is probably too low for the period of actual working, as these furnaces are rarely in blast continuously for the whole year.

The anthracite furnaces of Pennsylvania are remarkable for the high pressure (from 6½ to 7½ lbs. per square inch) of blast employed. The ores are similar to the *rock mine* of Sweden—*i.e.*, massive magnetite and hematite, yielding from 50 to 60 per cent. of iron.

The following are the charges and produce of two different furnaces :—

	Lehigh.	Lackawanna.
Ore . .	42¼ cwt. . .	38½ cwt. (52 per cent.)
Limestone .	29¼ ,, . .	14½ ,,
Coal . .	39¾ ,, . .	33 ,, .
Weekly make	248 tons (⅓ No. 1, ⅔ No. 2)	268 tons (all No. 3).

In the State of Indiana, the specular and red hematite ores from Lake Superior, Iron Mountain, and Pilot Knob, in Missouri, are smelted with the so-called *block coal*. This is a free-burning, non-caking splint coal, which is highly esteemed for iron-smelting purposes, and is used in the raw state. The furnaces are all of moderate size, from 50 to 60 feet in height, from 12 to 16, across the boshes, and 5 to 6 feet in width of hearth.

At Brazil (near Indianapolis), the furnace charges employed are as follows :—

1,545 lbs.	mixed ores (hematite, magnetite, scrap, and mill cinder.
475 ,,	limestone.
1,800 ,,	coal.

The yield is about 68 per cent., the furnace being tapped three times in the twenty-four hours.

The blast is heated by the waste gases to a temperature of 370° to 450°, and is delivered under a pressure of from three to four pounds to the square inch, through seven twyers, each 3½ inches in diameter.

The average daily consumption of coal is 70 tons, of ore 45 tons, and of limestone 16 tons; the average make of pig iron being 28 tons. The consumption of coal is therefore about 2½ tons per ton of pig iron made, or, reducing it to its equivalent in coke, about

1½ tons. The conditions of working, therefore, notwithstanding the high produce of the ores, are not nearly so economical as regards consumption of fuel as those of the Lancashire and Cumberland furnaces smelting hematite.

The ores used at this furnace are brought from very great distances, the native ore being more expensive in proportion to its produce than the richer hematite and magnetite of Missouri and Michigan.

The estimated make of pig iron in the United States from 445 furnaces in blast, in 1868, was as follows, classified according to the fuel employed :—

	Tons.
Anthracite	893,000
Coal and Coke . . .	146,000
Charcoal	310,000
	1,349,000

At Newark, in New Jersey, spiegeleisen is made from the residues obtained in the treatment of the mixed zinc and iron ores of Franklin, in the same State. The ore is an intimate mixture of franklinite and red zinc ore, with a massive green variety of willemite or silicate of zinc; it occurs in crystalline limestone, forming an irregular bed, which in places is 52 feet thick, the different minerals being very intimately mixed. A mixture of finely-crushed ore, with lime and anthracite, is heated in an oven-shaped calciner, having a cast-iron bed, perforated with numerous narrow slits, through which air is blown by a fan in sufficient quantity to burn the coal and oxidise the zinc vapour as it forms. The oxide of zinc produced in this process passes through a long series of condensing tubes and cooling chambers, the current being kept up by exhausting fans, until it is sufficiently cooled to be collected in bags made of cotton cloth. The residue remaining in the furnace after the removal of the zinc is a black cindery mass, containing the whole of the iron and manganese of the franklinite and the silica of the willemite, besides some undecomposed zinc oxide; it is estimated to contain 25 per cent. of iron, and 4 per cent. of zinc, and is smelted for spiegeleisen. The furnaces employed are very small, being only 20 feet high, and 7 feet across the boshes; the hot blast is of about 200° temperature, and a pressure of four pounds is used. The fuel used is anthracite, and some limestone is added as a flux. Four blank charges of clean slags are made in every twenty-four, to prevent scaffolding. Great difficulty is experienced in working the furnaces, owing to the large amount of zinc remaining in the ore, which deposits in the gas flues at the throat, and necessitates the use of an elaborate system of wrought-iron condensers for separating the oxide of zinc from the gases, before they can be burnt in the hot-blast stoves and steam boilers. The oxide of zinc obtained in cleaning out the condenser, being too much discoloured to use as paint, is sent to the spelter furnaces for reduction, and makes a very high quality of zinc. The consumption of fuel is very high, being at the rate of 3¼ tons per ton of iron. The weekly make of the furnace is about 25 tons. When making spiegeleisen, the slags are of the usual bright green colour characteristic of manganese; but when the furnace is too heavily burdened, and produces No. 2 iron corresponding to the German *weisstrahlig*, the colour changes to a deep brown. Owing to the large relative proportion of manganese to iron in the residues, the spiegeleisen produced is very rich in manganese, and at times is said to contain as much as 19 per cent.

The estimated production of pig iron in the principal iron-making countries of the world is as follows:—

			Tons.
In the United Kingdom, 1869	596	furnaces made	5,445,757
France, 1869	450	,,	1,356,000
*North Germany, 1869	360	,,	1,195,000
*United States, 1869	445	,,	1,349,000
Belgium	52	,,	450,000
*Russia	—	,,	300,000
Austria	—	,,	314,000
Sweden and Norway	253	,,	246,000
*Italy	—	,,	37,500
*Spain	—	,,	60,000

Quantities marked * are estimated.

The following is a more detailed list of the production of pig iron from the mineral statistics for 1869, showing the comparative importance of the different iron-making centres:—

Districts.	Furnaces.	Tons.
Northumberland and Durham	41	674,448
Cleveland (N. Riding of Yorkshire)	51	766,410
West Riding of Yorkshire	23	105,765
Cumberland and Lancashire	36	565,769
North Staffordshire	27	213,913
South Staffordshire	95	569,562
Shropshire (Colebrookdale)	23	197,443
Derbyshire	31	188,353
Lincolnshire	5	38,786
Northamptonshire	7	41,500
Wilts, Gloucester, Somerset	11	81,306
North Wales	6	38,530
South Wales	112	800,972
Scotland	128	1,150,000
	596	5,445,757

CHAPTER X.

OF THE CONSUMPTION OF FUEL AND DISTRIBUTION OF HEAT IN THE BLAST FURNACE.

THE theoretical distribution of the heat given out by the fuel in the blast furnace is found by comparing the sensible temperature and weight of the matters discharged, multiplied by their specific calorific capacities, with the heat produced by the combustion of the fuel and from other sources, according to the known laws of heat. The following example of a calculation of this kind, made on a French furnace, and exhibiting the results in the form of a debtor and creditor account, is taken from an excellent treatise by De Vathaire, recently published ("Etudes sur les Hauts Fourneaux," chap. vi. 72).

I. *Calculation of the Quantity of Heat absorbed in the different Operations of the Blast Furnace.*

The carbon burnt in the furnace is employed for three different purposes. These are:—

1. Heating of fixed and volatile matters.
2. Reduction of metallic oxides.
3. Restitution of heat absorbed during the reduction.

Let us select as an example a furnace working upon grey iron (No. 3), whose charges yield 40 per cent. of pig iron, with a consumption of coke 14 per cent. of ash, at the rate of 1,350 kilogrs. per ton (1,000 kilogrs.) of pig iron; the blast being heated to 300°.

The mean composition of the charge, including the ash of the fuel, is as follows:—

Peroxide of iron	1,344	equal to 950 iron, or 1,000 cast iron.
Silica . .	256	,, 649 of slag.
Lime . .	266	
Alumina . .	127	
Carbonic acid .	257	
Water . .	250	
	2,500	kilogrs. weight of charge per ton of metal.

Quantity of Heat carried out of the Furnace by the liquid Products. The number of units of heat contained in the products of fusion was found, by the calorimetric method of melting ice, to be—

330 per kilogr. of grey cast iron, and
550 ,, ,, slag.

The total quantity absorbed, therefore, per 1,000 kilogrs. of metal and 643 kilogrs. of slag, is

1,000 × 330 = 330,000 units of heat.
649 × 550 = 354,750 ,, ,,

Making together 684,750 ,, ,,

Quantity of Heat carried off by the Waste Gases. Out of the total amount of 1,350 kilogrs. of coke, 50 are taken up by the iron, and the remaining 1,300 (representing 1,118 of pure carbon) is volatilised, and passes out at the throat. To this must be added 70·1 kilogrs. derived from the carbonic acid of the flux, making a total of 1,188 kilogrs. of carbon volatilised per ton of pig iron.

The composition of the waste gases by weight was found to be as follows:—

Carbonic acid	12·80	containing	3·491	carbon.
Carbonic oxide	25·53	,,	12·215	,,
Hydrogen .	0·07		———	
Nitrogen .	61·60		15·706	,,
	100·00			

The amount of carbon in the gases being 15·707 per cent., the above quantity of 1,188 kilogrs. represents a total of 7,556 kilogrs., which, being discharged at a mean temperature of 200°, carry with them the following amounts of heat. This temperature is considerably lower than that usually observed in English close-topped furnaces. At Clarence, in Durham, Bell found it to be between 500° and 600°.

	Weight.		Specific heat.		Sensible heat.				Total units of heat.
Carbonic acid .	12·80	×	0·221	×	200	×	$\frac{7566}{100}$	=	42·810
Carbonic oxide	25·53	×	0·288	×	do.	×	do.	=	111·270
Hydrogen .	·07	×	0·903	×	do.	×	do.	=	·958
Nitrogen. .	61·60	×	0·275	×	do.	×	do.	=	256·370
Water .	250 kilogrs.	×	1·00	×	750			=	187·500
									598·908

The quantity 750 in the last line is made up of the sensible heat, 200 plus 550, rendered latent by conversion of the water into steam.

Quantity of Heat absorbed in the Reduction of Oxides of Iron. The amount of carbon required for the reduction of an iron ore is proportional to the number of equivalents of oxygen contained, or taking into account the difference of atomic weights, is equal to three-quarters of the total weight of oxygen, the equivalents of carbon and oxygen being to each other as 6 to 8 Therefore—

Protoxide of iron	cntg.	77·78	iron and	22·22	oxygen	requires	214·2	carbon
Magnetic oxide	,,	72·41	,,	27·59	,,	,,	285·6	,,
Peroxide . .	,,	70·00	,,	30·00	,,	,,	321·75	,,

per ton of iron reduced.

The reduction of the oxide in the furnace is entirely performed by carbonic oxide; but as the carbonic acid so produced is, by the secondary action of ignited carbon, immediately re-converted into carbonic oxide, the result is much the same as if it had been effected directly by solid carbon, as it is only near the top of the furnace, where the temperature is comparatively low and the current rapid, that any carbonic acid can exist as such.

The production of carbonic oxide by the action of carbon upon oxide of iron is attended with a considerable absorption of heat. Iron, when burnt in oxygen, evolves 6,216 units of heat for each litre of oxygen consumed (1·436 grammes). The inverse phenomenon of reduction, therefore, renders the same amount of heat latent. But 1 litre of oxygen (1·436 grs.), combining with 1 litre of carbon vapour (1·077 grs.) to form two litres of carbonic oxide, only gives out 1,598 units of heat, which, deducted from the 6,216 rendered latent, leaves 4,618 as representing the cooling effect produced for each litre of oxygen displaced from the iron, and converted into carbonic oxide by a consumption of 1·077 grs. of carbon.

The consumption of carbon per ton of iron reduced, and the heat absorbed, is therefore with

	Kilogrs					
Peroxide of iron .	321·75	of carbon	and	1,368,550	units	of heat.
Magnetic oxide .	285·6	,,	,,	1,270,227	,,	,,
Protoxide of iron .	214·2	,,	,,	870,704	,,	,,

In order to simplify the calculation, the amount of heat given out on combustion by the carbon employed in reduction will be for the moment neglected, and only the absorption of heat by the separation of the iron and oxygen brought into account. This is for the different oxides as follows:—

Oxides.	Kilogrs.	Units.	Kilogrs.	Units.	Kilogrs.	Units.
Fe^2O^3	1,000	1,298,610	1,429	1,855,700	1,341	1,744,358
Fe^3O^4	„	1,194,300	1,381	1,649,300	1,282	1,550,342
Fe O	„	961,840	1,285	1,236,000	1,208	1,161,840

The third column in the above table shows the quantity of heat absorbed in the reduction of a ton of each oxide; the fifth, the amount corresponding to the quantities of each oxide required to make a ton of iron; in the seventh, a similar series of quantities calculated to the ton of pig iron, supposing it contains 94 per cent. of iron and 6 of foreign matters.

Heat absorbed by the Reduction of Vapour of Water. The hydrogen contained in the gases of the furnace is derived from the decomposition of steam introduced with the blast. The quantity, ·07 per cent. corresponds to 47,666 kilogrs. of steam per ton of metal produced, or ·00786 of the weight of the air injected, a result corresponding fairly with the hygrometrical condition of the atmosphere at the time. The amount of heat absorbed by the separation of 4·596 kilogrs. of hydrogen per ton of metal is—

$$4{\cdot}596 \times 31{,}742 = 159{,}681 \text{ units of heat:}$$

34,742 being the calorific power of hydrogen burning to water.

II. *Calculation of Heat developed in the Furnace.* This is derived from two principal sources, namely,—

1. Heat produced by the combustion of fuel; and,
2. Heat brought into the furnace by the hot blast.

The heat produced by the combustion of 1,118 kilogrs. of carbon is made up of two quantities, part being derived from the formation of carbonic acid, while the remainder results from the imperfect combustion of the larger portion of the fuel to carbonic oxide.

In addition to the above quantity of 1,118 kilogrs., 70 kilogrs. of carbon contained in the gases are derived from the carbonates of the charge, making a total of 1,188 kilogrs., distributed as follows in the gases:—

As carbonic acid	3·491	per cent. or in 1,188 kilogrs.	264	kilogrs. carbon.
,, carbonic oxide	12·216	,, ,,	924	,,
	15,707		1,188	

From this amount, however, must be deducted the 70 kilogrs. contained in the carbonic acid of the carbonates which has been volatilised as such, and is not derived from combustion of carbon in the furnace. The total amount disposable for heating purposes therefore becomes—

194 kilogrs. burnt to carbonic acid.
924 ,, carbonic oxide.

Multiplying these by their respective calorific powers, we obtain—

194 × 7,170 = 1,390,980
924 × 1,386 = 1,280,664

2,671,644 units of heat

as the total amount of heat given out by the fuel under the conditions of the experiment.

Heat introduced by the Blast. The quantity of air blown into the furnace is to be calculated from the proportion of nitrogen found in the waste gases.

The amount of nitrogen in the gases is found to be

61·6 per cent., air containing 76·9 per cent. The amount corresponding to 7,556 kilogrs. of gases evolved in the production of a ton of metal is therefore—

$$\frac{7{,}556 \times 0{\cdot}616}{0{\cdot}769} = 6060{\cdot}6 \text{ kilogrs. of air.}$$

Supposing this to be heated to the temperature of 300°. the extra amount of heat from this source, the calorific capacity of air being 0·2669, is—

$$6060{\cdot}6 \times 0{\cdot}2669 \times 300 = 485{,}272 \text{ units of heat.}$$

The small amount of hydrogen contained in the gases is derived from the decomposition of steam contained in the air by ignited carbon. As the amount of heat absorbed in this decomposition has been deducted, the quantity brought in by the heated water vapour must be taken into account as follows:—

5·2962 kilogrs. of hydrogen contained in the gases correspond to 47,666 kilogrs. of water, containing 300° of sensible and 550° of latent heat; or, in all,

47,666 × (300 + 550) = 41,506 units of heat;
which, when added to 485,272 ,, ,,

gives a total of 526,778 ,, ,,
as the contribution of the hot blast to the heat of the furnace;

or about 20 per cent. of the whole amount of heat expended, a theoretical determination which fairly corresponds with the saving of 20 to 30 per cent. of fuel, obtained in practice by the use of hot blast.

On comparing the two sides of the account, we obtain the following balance sheet of heat developed and expended per ton of metal.

Cr. Causes of Absorption of Heat.

	Units.
Heat carried out of furnace by 1,000 kilog. of molten metal	330,000
„ „ „ 619 „ „ slag .	354,750
„ „ „ the waste gases . . .	598,908
„ rendered latent by reduction of 1,343 kilog. of peroxide of iron .	1,744,358
„ „ „ 4,596 „ hydrogen	159,681
Total amount of heat expended . . .	3,187,697

Dr. Sources of Heat.

Heat given out by combustion of carbon	2,671,644
„ introduced by the hot blast air	526,778
Total amount of heat employed . . .	3,198,422

leaving a balance of 10,725 units unaccounted for—a quantity far within the probable limits of error in the computation. A few minor sources and causes of absorption of heat have been neglected, from the want of numerical data for their calculation. These are :—

1. Heat absorbed by the reduction of silica, the calorific power of silicon being undetermined. If it be the same or nearly that of carbon, the reduction of from 15 to 20 kilogrs. of silicon per ton of metal will require from 100,000 to 150,000 units of heat.

2. Latent heat of volatilisation of carbonic acid upon the decomposition of the carbonates. This is probably trifling in amount, judging from the small quantity of fuel consumed in lime-burning.

3. The cooling caused by the dilatation of the blast, from the pressure of 9 or 10 centimetres of mercury to that of the atmosphere.

A source of heat not taken into account is that given out by the combination of silica with earthy bases in the formation of the slag.

Supposing now the blast to be heated to 600° instead of 300°, the total available amount of heat becomes 3,725,220—an increase of about 16 per cent. on the former quantity. A saving of from 17 to 18 per cent. of fuel was effected by the introduction of Cowper's stoves, producing a similar increase of temperature. If, therefore, the products of combustion remained unaltered, the saving of fuel would appear to be directly proportional to the extra heat introduced by the blast; but this is by no means certain, and it is probable that a part of the economy is due to more perfect combustion. The heating up the large quantity of inert nitrogen, which in weight considerably exceeds the whole amount of solid materials, fuel and fluxes taken together, before introducing it into the furnace, must obviously prevent a great waste of heat in the hearth; and this saving would be proportionately greater the less perfect the combustion and the smaller the amount of heat developed by the fuel, supposing the temperature of the blast to be constant.

In the particular case before us, it will be seen that only about 17 per cent. of the whole quantity of fuel burnt is converted into carbonic acid, with the product of a maximum of heat, the remaining 83 per cent. giving rise to less than one-half of the total amount evolved. Supposing the combustion to have been complete, 8,016,060 units would have been evolved, so that, by the imperfect combustion, two-thirds of the total heating power of the fuel is undeveloped.

The production of carbonic oxide in considerable quantity is, however, a necessary condition to the proper working of the furnace; the entire conversion of the fuel into carbonic acid could not be allowed, even were it possible, as the maintenance of a reducing atmosphere is of primary importance. The utmost that can be done is to increase the relative amount of carbonic acid by the use of compact fuel in large masses, a fine state of division being favourable to the production of carbonic oxide, on account of the larger surface and increased resistance offered to the passage of the gas.

The effective heating power of the gases may be computed from the analyses given above. The calorific power of carbonic oxide being 2,478 units, and of hydrogen 34,742 units per kilogramme, the total amount obtainable from the gases evolved, per ton of coke burnt in the furnace, is 3,808,492 units of heat, or as much as would be produced from the combustion of 616 kilogrs. of coke. It therefore appears that 61 per cent. of the fuel charged in the furnace remains available in the gases.

If now the consumption of coke be 30 tons per day, the gases, if applied to steam boilers, will by their combustion raise steam for an engine of 257 horse power. As, however, not more than 80 horse power is required for working the blast engine, there will evidently be a sufficiency remaining for heating the stoves and other accessory operations.

Composition of the Gases of the Furnace at different Heights. This subject has been investigated at different times by Bunsen, Ebelmen, Scheerer, Playfair, Rinman, Tunner, and others, both in coke, charcoal, and coal-fed furnaces. The results arrived at are generally similar, allowance being made in the first instance for the products of distillation where raw mineral fuel ores or fluxes are used. The ultimate products include the whole of the carbon contained in the fuel, less the amount required for carburising the metal produced, as carbonic oxide and carbonic acid in combination, with the oxygen of the air blown in at the twyers, and that set free by the reduction of the ores, the nitrogen of the air, and small quantities of hydrogen and hydrocarbons, arising from the decomposition of water vapour introduced by the blast.

ANALYSES OF WASTE GASES FROM THE TOPS OF BLAST FURNACES.

PERCENTAGE BY VOLUME.	I.	II.	III.	IV.
Nitrogen	55·35	55·62	57·79	57·06
Carbonic acid	7·77	12·59	12·88	11·39
Carbonic oxide	25·97	25·24	23·51	28·61
Marsh gas	3·75	—	—	0·20
Olefiant gas	0·43	—	—	—
Hydrogen	6·73	6·55	5·82	2·74

No. I. Alfreton, Derbyshire, charge containing calcined argillaceous ore, limestone flux, and raw coal.
„ II. Audincourt, France, charge containing brown hematite and forge cinders, limestone flux, wood, and charcoal.
„ III. Clerval, France, charge containing brown hematite, limestone, and charcoal.
„ IV. Seraing, Belgium, charge containing brown hematite, mill cinders, limestone, and coke.

It will be seen that the principal component of these gases is nitrogen, which is brought in by the blast, and passes through the column of materials without taking part in the chemical changes involved in the reduction of the ore and the combustion of the fuel. The proportion is, however, considerably less than in atmospheric air, and as practically none is absorbed, it follows that the considerable increase observed in the amount of oxygen—from 12 to 18 per cent. in volume—must be derived from the solid materials of the charge. The principal source of this increase is to be found in the decomposition of the oxides of iron in the ore, while a further but much smaller quantity may be derived from the reduction of silica to silicon in hot blast furnaces working on quartzose ores. The proportion of carbonic acid to carbonic oxide diminishes progressively in the gases taken at lower levels, until, in the upper part of the hearth, they are found to consist almost entirely of nitrogen and carbonic oxide.

According to Tunner, the temperature prevailing in the Styrian furnaces at a point about 3 inches above the twyer level was only 1,450° when making white iron, and 1,750° with grey iron. At the twyers wrought iron melted easily, but not platinum, so that the temperature was assumed as being higher than 1,900°, and less than 2,500°, or about 2,200°.

The furnace at Eisenerz, upon which these experiments were made, the zone of maximum temperature was approximately spheroidal, extending inwards and upwards for about 6 or 7 inches in front of each twyer. It is only within these small spaces that carbonic acid is produced by the complete combustion of the fuel. The amount of carbonic oxide evolved by combustion is greatest with light, easily combustible fuel, such as soft-wood charcoal, and a low temperature and pressure of blast. In the same way the transformation of carbonic acid into carbonic oxide is more readily effected under similar conditions than with harder fuel, such as coke or anthracite. In charcoal furnaces, therefore, carbonic oxide prevails even at the lowest level, while at a very small height above the twyer carbonic acid is almost entirely absent. Higher up the quantity of the latter gas increases, because in the less highly heated parts of the furnace the oxidation of carbonic oxide by the oxygen of the ore goes on more energetically than the converse reduction of carbonic acid to carbonic oxide by carbon. The temperature at which the reduction of the ore commences is, in the case of spathic ores, stated to be from 600° to 700°. Reduction and carburisation of the metal are more easily effected, and with a less consumption of fuel, when charcoal is used than is the case with coke, as, although with the latter a more intense heat may be obtained in the lower part of the furnace, the production of reducing gases will be diminished; for the more compact the fuel, and the denser and hotter the blast, the greater will be the amount of carbonic acid produced at the twyers, and consequently the higher the temperature in the hearth. But as the carbonic acid so produced is less easily converted into carbonic oxide by coke than by charcoal, there is likely to be a smaller production of reducing gases.

The manufacture of pig iron, therefore, is attended with a larger expenditure of fuel when coke is used than is the case with charcoal, but when only heat is involved, as in remelting pig iron for founding, the same weight of iron can be melted with a smaller weight of coke than of charcoal.

In furnaces worked with raw coal, the gases, in addition to the products of combustion, contain small quantities of condensible vapours, especially tarry matters and ammonia, which it has been proposed to collect and utilise in a similar manner to the waste products of gas works. Bunsen and Playfair suggested that the ammonia might be collected as sal-ammoniac by passing the gases through a chamber containing hydrochloric acid. More recently D. Price has proposed the injection of finely-divided water into the main gas conduit, as well as the use of hydraulic mains, such as are employed in gas works for the same purpose.

The gases of blast furnaces usually carry over a considerable quantity of finely-divided solid matter in the form of dust, which deposits in the throat flues and gas culverts, and requires to be removed from time to time.

The following is the composition of the dust from two different localities:—

	Dowlais, South Wales (Riley).		Clarence, Cleveland (Bell).
Silica	30·33		34·82
Alumina	8·43		16·00
Peroxide of iron	47·05		8·20
Peroxide of manganese	1·77		—
Lime	2·30		12·15
Magnesia	1·13		0·57
Protoxide of zinc	—		4·60
Potash	1·80		0·40
Soda	0·36		6·85
Water	0·93		5·60
Sulphate of lime	4·42	Sulphuric acid	8·80
Phosphate of lime	0·75	Chlorine	1·56
	99·27		99·55

At the Concordia furnace, near Aix-la-Chapelle, where brown iron ores containing a considerable quantity of oxide of zinc are smelted, the gases are simply washed by passing them through a pipe of large section, kept about half filled with water, by which means a portion of the zinc fume is deposited; sufficient is, however, kept in suspension to render it necessary to clear out all the flues at very short intervals. When the main gas pipe at the throat is obstructed, the furnace is allowed to go down until the top of the column of materials is about 9 feet below the charging plate. The surface is then cooled with water and covered with iron plates, forming a platform for the workmen who are employed in clearing out the deposit. The oxide of zinc recovered is sold to the neighbouring zinc works.

CHAPTER XI.

VARIETIES AND COMPOSITION OF PIG IRON.

THE produce of the blast furnace is divisible into several different qualities, which, for practical purposes, are determined by the appearances presented by a freshly-fractured surface, a certain number of pigs taken from each cast being broken for the purpose. The numerous gradations in the scale are mainly dependent upon colour or degree of greyness, texture or size, of the crystalline plates, and their uniformity and lustre. The largest-grained brilliant and graphitic dark grey metal is known as No. 1 pig, while the smaller-grained varieties with diminishing lustre and colour are distinguished by the higher numbers as far as No. 4.

Beyond this point, when the metal ceases to be grey, the numerical scale is not used, the remaining qualities being known as mottled, with a further division in some instances into weak and strong mottled, and white, the last being the lowest. This classification is subjected to slight variations in different districts, as in the following examples of scales used in differents parts of England:—

Cleveland	Nos.	1 . 2 . 3 . 4 . 4 Forge.	Mottled.	White.
Lancashire hematite	„	1 . 2 . 3 . 4 . V.	Mottled.	White.

The grey numbers as far as No. 3 are also called foundry or melting pigs, the lower qualities, which are only adapted for conversion into malleable iron, coming into the class of forge pigs. In Lancashire and Cumberland two extra classes are made, known as Bessemer iron Nos. 1 and 2. These command higher prices than the same numbers in the ordinary scale.

The relative greyness or whiteness of pig iron furnishes no real standard of quality as compared with the produce of other districts, but is rather an indication of the working conditions of the furnace. Other things being equal, white cast iron can be more readily and cheaply produced than grey, as the same amount of fuel is made to carry a larger burden of ore, and the charges are driven more rapidly. As, however, it can only be used for forge purposes, while the more expensive grey metal is available for making either castings or malleable iron, it is usually sought to diminish its production as much as possible, except in special cases, where quantity of make or an extreme economy of fuel is desired.

White cast iron melts at a lower temperature than grey, but becomes less perfectly fluid: in cooling it passes through the pasty or semi-fluid condition, and contracts very considerably on solidification. Grey cast iron, on the other hand, expands in becoming solid, so as to be capable of filling up the smallest cavities and depressions of a mould. When both kinds of metal are contained in the hearth of a blast furnace at the same time, the whitest being the heaviest, goes to the bottom, and will be found in the first pigs obtained at the next cast. The method of flowing is also indicative of the quality of the molten metals to an experienced eye. White iron flows in a sluggish stream, throwing out brilliant sparks, while the grey foundry qualities run perfectly fluid and without sparks.

In Sweden, and other countries where the practice of casting in metal moulds is adopted, the fractured surface of the metal, even when perfectly grey, is whitened by the chill to a considerable depth. Another class of metal often obtained under similar circumstances consists of about equal parts of white columnar and fine dark grey iron in alternating stripes, or the latter may be interspersed in ragged patches, stars, or spots through a white ground. These varieties are in great request for conversion into malleable iron, as they approximate in character to the mixtures of grey pig iron with refined metal that are found to be most advantageous for such purposes. The so-called steel iron or white columnar pig of Siegen, and the flowery pig iron of Styria (*blumige floss*), are of this character. Common white iron, made with a heavy burden of cinders, is dull in colour, and presents a rough, honeycombed appearance on the upper surface of the pig; it usually contains a considerable amount of phosphorus and sulphur, and though very hard, may be easily broken.

In the United States, the white pig iron produced in New Jersey from the residues obtained in the treatment

ANALYSES OF PIG IRON FROM VARIOUS SOURCES.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
Carbon combined . .	2·35	1·43	3·17	3·570	2·50	5·04	1·07	4·10	2·390	3·22	4·18
„ graphitic . .	2·40	2·02	0·12				3·39	—			
Silicon	1·17	0·92	0·37	0·130	0·16	0·41	1·81	0·23	5·730	3·02	1·92
Manganese . . .	5·42	2·02	7·39	0·610	0·10	7·57	1·08	2·37	1·33	0·11	0·02
Sulphur	0·06	0·04	0·11	0·010	0·04 Cu	0·08	0·043	0·03	0·119	—	0·05
Phosphorus . . .	trace	0·04	trace	trace	0·11 Ca	0·16 Cu	0·006	0·073	0·131	0·06	0·08
Vanadium	—	—	—	trace	—	—	—	—	—	—	0·12 Ca
Titanium	—	—	—	—	—	—	—	—	—	—	—
Iron	88·60	94·08	88·84	95·681	—	86·74	—	—	—	—	93·94

No. I. Grey; No. II. mottled; No. III. white, from Lölling, in Carinthia, smelted with charcoal from spathic ore. Rosthorn.

„ IV. White forge pig smelted with charcoal from raw spathic ore at Eisenerz, in Styria. Müller.

„ V. „ „ „ magnetite and specular schist, Langshytta, Dalarne. Rinman.

„ VI. Spiegeleisen; No. VII. grey Bessemer pig No. 2, coke smelted from spathic and brown iron ores, Hochdahl, Siegen. Jordan.

„ VIII. Spiegeleisen; No. IX. grey Bessemer pig, from similar ores, Towlaw, Weardale. Riley.

„ X., XI. Grey foundry iron, from red hematite, the former from Whitehaven, the latter from Cleator, in Cumberland. Abel.

ANALYSES OF PIG IRON FROM VARIOUS SOURCES.

	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.
Carbon combined .	5·48	0·08	0·28	2·30	—	—	—	0·800	2·42	2·80
„ graphitic .		3·40	3·13		2·99	2·61	3·15	0·754		
Silicon	0·20	2·73	0·88	4·88	0·97	1·71	1·05	3·365	0·36	1·85
Manganese	4·50	0·64	0·37	2·22	—	0·27	1·14	0·298	—	—
Sulphur	0·08	—	0·17	0·02	0·05	0·05	0·05	0·702	0·87	0·14
Phosphorus	0·15	1·33	1·23	0·57	0·50	0·29	0·29	1·368	1·08	1·66
Vanadium	0·30 Zn	0·38	—	—	—	—	—	—	—	—
Titanium	—	—	0·14	—	—	—	—	—	—	—
Iron	88·30	91·37	93·66	89·45	—	—	—	92·713	95·27	93·55

No. XII. Spiegeleisen smelted with anthracite, from Franklinite.
„ XIII. Acklam No. 1 pig; No. XIV. Clarence No. 3 pig, both from Cleveland stone.
„ XV. Coalbrookdale best foundry iron, from argillaceous ores, cold blast coke smelted. Noad.
„ XVI. Bowling No. 1 cold blast pig. Abel.
„ XVII. Ystalyfera No. 3 hot blast, from argillaceous ores smelted with anthracite. Abel.
„ XVIII. South Staffordshire, from native argillaceous mine, Ulverstone red, Dean Forest, and Froghall brow hematite. Abel.
„ XIX. Northamptonshire hot blast white mottled. Henry.
„ XX. South Wales common white pig; No. XXI. South Wales grey cinder pig. Noad.

of franklinite after the oxide of zinc has been removed enjoys a very high reputation for use in the manufacture of chilled articles, especially crushing and forge rolls and stamp heads. In foundries where the remelting is performed in reverberatory furnaces, dark grey iron can be used to advantage, and the quality of the metal may be greatly improved by the addition of a proportion of malleable scrap iron.

The following are the appearances to be noted on the fractures of different classes of foundry iron according to Guettier:—

A moderately large grain of slight lustre, mottled with fine patches having a tendency to whiteness, indicates the highest degree of resistance.

A smaller grain, but similarly dull, with a mottled grey base, marks the quality of metal best suited to resist tractive strains.

A somewhat fibrous grain, terminating in fine jagged pyramidal points on the fractured surface, with a close regular grey base, is a mark of great transverse strength

A fine-grained grey metal, bordering upon mottled, when the fracture is small-grained and even, and not in flat broad plates, is the best for resisting compression.

The varieties presenting the least resistance are those that are full of graphite of a blackish-grey colour and large brilliant grain, or of an irregular grain upon a shining base, and the mottled white kinds in which there is no granular structure apparent.

Guettier found that No. 1 Scotch pig reached its maximum strength after the eighth melting. Fairbairn found that the same point was reached with No. 3 pig (Eglinton) after twelve meltings.

Those varieties of cast iron that are smelted from spathic ores containing manganese in considerable quantity are also white and intensely hard, the fractured surface presenting an aggregate of bright lamellar crystals, sometimes nearly an inch across, forming the so-called specular pig (spiegeleisen). Unlike ordinary white iron, it contains a very large amount of carbon, all of which is in chemical combination. The circumstances favouring its production have been noticed at p. 223. Manganese is always present, but the amount may vary very considerably without affecting the large lamellar crystalline structure.

Strength of Cast Iron. The resistance of cast iron to strains applied in different directions is subject to very considerable variation, according to its composition and quality. The softest, or No. 1 pig, is usually deficient in strength as compared with the lower qualities made from the same ores. It is customary in founding, therefore, to work with two or more different kinds of metal, in order to obtain mixtures combining the qualities of the different components, or sometimes a proportion of malleable scrap or refined iron is added to grey iron for the same purpose.

Silicon is generally reputed to be a source of weakness in cast iron, such as the dark grey No. 1 Scotch pig smelted from blackband; and it is for this reason, probably, that hot blast metal is of smaller tenacity than that made with cold blast from the same materials.

The following are the maximum and minimum limits of strength in British pig iron, as deduced from observations made at Woolwich in 1856-59:—

	Minimum.	Maximum.
Specific gravity . .	6·886 . .	7·289
	Per square inch.	
Tensile strength . .	4·85 tons .	14·05 tons
Transverse	1·37 „ .	4·47 „
Torsional	1·74 „ .	3·44. „
Crushing	22·54 „ .	58·42 „

The transverse resistance was measured by the force necessary to break a bar of an inch square when loaded at the same distance from the point of support. The torsional strength was measured by applying a twisting strain to a bar reduced to the same ratio at a distance of 8 inches from its bearings.

The lowest values were obtained with pig iron smelted from sandy brown hematite, and the highest from hematite or argillaceous carbonates, either alone or mixed and smelted with cold blast.

The chemical composition of pig iron is subject to considerable variation, as will be seen by the preceding table, which comprises analyses from the principal British and foreign iron-smelting districts.

CHAPTER XII.

METHODS OF MAKING WROUGHT IRON DIRECTLY FROM THE ORE.

THE chief modern representative of the bloomeries or hearths by which iron was produced from the earliest ages down to the introduction of the blast furnace is the so-called Catalan or Corsican forge, which still survives in the Pyrenees, and a few other isolated localities in the South of Europe. As it is of comparatively small importance in the economy of modern iron-making, a very brief notice will suffice.

The hearth, or furnace, employed in this process, is represented in longitudinal section in Fig. 22. The bottom of the hearth is of refractory sandstone, and before using, is lined or brasqued with a coating of charcoal dust or breeze. The front wall, or face, *a*, is curved outwards so as to increase the capacity of the hearth at the top. The opposite side is provided with a twyer made of sheet copper, inclined at an angle of from 30 to 40 degrees. The tapping hole for removing the slag is placed in one of the side walls, which is also covered with an iron plate, forming a point of support for the tool used in working the contents of the hearth, and removing the spongy mass or ball of iron produced.

The blast is usually produced either by a *trompe*, or a wooden engine with a square piston: its pressure never exceeds 1¼ to 1¾ inches of mercury.

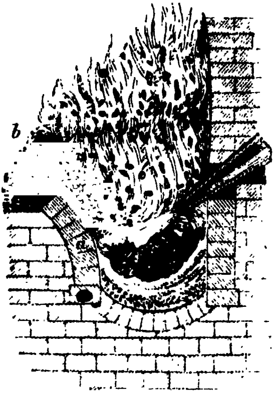


Fig. 22.—Catalan Finery.

The method of conducting the operation is as follows:—After repairing the lining of the hearth bottom, a pile of ore, usually a rich and easily-reducible brown hematite, occupying from one-third to one-half of the total contents of the hearth, is placed at *b*, parallel to the curved wall, the remaining portion, to the twyer wall, being filled with charcoal. The whole is then covered with charcoal dust and small ore (*greillade*) moistened with water.

At first only a gentle blast is used, and as soon as flame appears at the surface, it is damped by a fresh application of *greillade* in order to prevent too rapid combustion, and the falling in of the heap before the reduction of the oxide of iron to the metallic state is effected. The preliminary stage lasts about two hours, after which the blast is turned full on, and the slags are tapped off. The workman then pushes the heap of ore further into the hearth by means of an iron bar introduced between it and the front wall. The reduction commences at the bottom of the heap with the formation of spongy masses of iron, which, as they appear, are pushed forward by the workman towards the twyer, in order to facilitate the separation of the metal from the slag by the liquation of the latter. The progress of the work is chiefly guided by the character of the slags, which are very liquid when highly charged with protoxide of iron, and stiff or pasty when deficient in bases. In the latter case the necessary fluidity is imparted by the addition of finely-divided ore in small quantities, which is allowed to dissolve in the slag without being reduced to the metallic state. This is, in fact, one of the essential points of the process, a portion of the ore being intentionally expended in fluxing the silica, in addition to the earthy bases associated with the peroxide of iron, in order to obtain an easily-fusible slag, which in its turn reacts upon the reduced masses of spongy metal, and prevents the assimilation of carbon and the formation of cast iron. Perfect liquidity of the slag is also desirable in order to facilitate its removal during the subsequent forging.

When the whole of the charge has been reduced, the blast is stopped, and the spongy masses in the hearth are worked together into a lump, or ball, which is lifted out and carried to the hammer, where it is forged, or *shingled*, to a rough bar, or *bloom*. During the first period of the process, while the ore is being reduced, the bloom obtained from the preceding charge, after having been cut up into several pieces, is reheated in the upper part of the hearth, and drawn out into bars under the hammer.

The iron produced in the Catalan forge is usually more or less hard and steely, though this depends in great part on the manipulation. By increasing the angle of inclination of the twyer, and keeping a large amount of slag in the hearth, the decarburisation of the spongy mass is facilitated, and a softer iron is obtained than is the case when the ore is allowed to be reduced slowly, and to remain in prolonged contact with the fuel; these conditions being favourable for the production of what is known as steely iron, or natural steel.

The slags produced in this process consist essentially of tribasic protoxide silicates, the principal base being protoxide of iron; but lime, magnesia, and protoxide of manganese are generally present in greater or less quantity. The silica usually exists in the ore in a free state as quartz.

Although the presence of several bases is advantageous as tending to produce a fluid slag, it is especially necessary that the amount of the earthy bases, lime and magnesia, should be small, as their silicates are too refractory to be properly melted at the temperature obtained in the hearth. The conditions governing the formation of slags in the Catalan forge are therefore exactly the reverse of those sought to be obtained in the blast furnace, where the scorification of protoxide of iron is prevented by the use of a large amount of lime as a flux for the silica in the charge. It will be shown subsequently that the same considerations are involved in all processes for the conversion of cast into malleable iron. Whenever silica or silicon is present, it is always eliminated as a silicate at the expense of a portion of the metal, and, at the same time, the highly basic silicate so formed, when brought into contact with molten cast iron, acts upon the combined carbon of the latter, with the production of carbonic oxide and metallic iron. It will be remembered that the nearest approach to this reaction observed in the blast furnace is when the cinder is black and scouring, corresponding to the production of white iron poor in carbon.

The weight of ore treated in a hearth of the largest size in one operation lasting six hours is about 9½ cwt., containing 45 to 48 per cent. of iron, the fuel consumed about 10¾ cwt., and the produce of finished bar iron about 3 cwt. The average consumption of materials per 100 lbs. of bar iron is, of ore 312 lbs., and charcoal 340 lbs., or 100 lbs. of ore in good work should yield 31 lbs. of bar iron, and 41 lbs. of slags containing 30 per cent. of iron. Of the total contents of the ore, therefore, 71 per cent. is reduced to the metallic state, while the remaining 29 per cent. is expended in the slag. The ore in question contains about 14 per cent. of silica.

The dimensions of the hearth vary in different districts; the smallest, or Catalan fire, in use in the central and eastern parts of the Pyrenees, is 20 inches in length and breadth, 16 inches total depth, 9 inches measured from the twyer to the hearth bottom, and takes a charge of 3 to 4 cwt. of ore. The Navarrese hearth, employed in French and Spanish Navarre and Guipuscoa, is 30 inches long, 24 inches broad, and 16 inches deep from the twyer to the bottom; the charge weighs from 5 to 6 cwt. The largest, or Biscayan hearth, is 40 inches long, 30 to 32 inches broad, and 24 to 27 inches in total depth, or from 14 to 15 inches below the twyer. The charges are from 7 to 9 cwt., as given above.

Various processes for the direct production of wrought iron from the ore have been proposed, differing from the Catalan forge, in the use of a closed vessel, such as a gas retort or fire-brick chamber, for the reduction, which is effected at as low a temperature as possible, either by the direct contact of finely-divided carbon, or in a current of reducing gases produced by the passage of air over red-hot coal in a special gas generator. The spongy masses of iron, after removal and cooling under a covering of charcoal, are welded in open hearths or reheating furnaces, with or without previously undergoing a mechanical separation from the earthy matters by crushing and treatment with electro-magnetic apparatus. As these methods are only applicable to the treatment of easily-reducible ores, and are essentially slow in work, giving only a small production from a plant of considerable extent, as compared with the old open fire, they have not as yet been found to possess sufficient advantages to be generally adopted on the large scale.

At Santa Aña de Bolueta, in Biscay, Gurlt's process of reducing the rich brown hematite of Sommorosteo, containing 68 per cent. of iron, by means of carbonic oxide, has been tried with the following results. The furnace has a shaft like an ordinary blast furnace, communicating with a series of gas generators near the bottom. When three charges were made daily, 72 cwt. of ore and 18$\frac{3}{4}$ cwt. of charcoal yielded 23·8 cwt. of spongy metallic iron, which was removed while still hot in iron barrows, and allowed to cool under a covering of charcoal dust. The subsequent welding of the sponges or balls was effected in an ordinary Catalan fire, the waste being about 50 per cent. by weight, and the consumption of charcoal equal to the weight of the finished bars produced. The total consumption was, therefore, per 100 lbs. of bars made, 174 lbs. of charcoal and 285 lbs. of ore; the loss of iron, amounting to nearly one-half, was larger than in the ordinary Catalan process, but a considerable saving of fuel was effected.

In India wrought iron is made directly from the ore, either in shallow hearths with an artificial blast, or in furnaces with shafts, which may be worked with a blast, or by a natural draught, the former resembling the Catalan forge, while the latter may be compared to the lump or wolf furnaces which prevailed in Europe before the introduction of the flowing or modern blast furnace. In either case the dimensions are small, as are also the blooms produced, which vary from 20 lbs. to 2 cwt. In the Burmese furnaces, which depend upon natural draught, the shaft is excavated in the face of a bank exposed to the prevailing wind, from 10 to 15 feet high, a number of conical pipes or nozzles being inserted in an opening at the lower part, corresponding in position to the tymp in an ordinary blast furnace. This primitive system of construction is said to have been used by the ancient Celtic inhabitants of the Rhenish hill countries, heaps of slags being found in Nassau, on the tops of bare swelling downs far away from water-courses, under circumstances which indicate the probability of their having been produced in furnaces of this class.

American Bloomary Process.—Although the old process of making iron directly from the ore has been completely abandoned in Germany, it is still employed to a very considerable extent in the United States, where it was introduced early in the eighteenth century; and has latterly been employed in Canada for the treatment of the black magnetic and titaniferous sands of the Labrador The following description of the process has been given by Dr. Sterry Hunt:—

The hearth or furnace, also known as the bloomary fire, Jersey or Champlain forge, varies in length and breadth, in different localities, from 27 by 30 to 28 by 32 inches, and the depth from 20 to 25 inches above the twyer, and from 8 to 14 inches below. The sides are made of cast-iron plates, and the bottom usually of beaten earth or cinders; but in the best-constructed hearths a hollow casting, cooled by water, is preferred. At East Middlebury, in Vermont, the bottom plate is 4 inches thick, with a hollow space of 2 inches within it. The side plates, which are $1\frac{1}{4}$ inches thick, are slightly inclined inwards, and rest on ledges on the bottom plate. A water-box, measuring 12 by 8 inches, is let into the twyer plate; and the water, after cooling the twyer, passes through the bottom plate. The twyer is placed 12 inches above the bottom, at such an inclination that the blast may strike the middle of the hearth. It is of segmental form, measuring 1 inch in height by $\frac{3}{4}$ inch wide. In front of the furnace, at a height of 16 inches above the bottom, is placed a flat iron hearth, 18 inches wide. The side plate beneath it is provided with a tap hole, for drawing off the cinders from time to time. The cast-iron plates used in the construction of these furnaces last for two years.

The blast employed has a pressure of from $1\frac{1}{2}$ to $1\frac{3}{4}$ lbs. to the square inch, and is heated by passing through a stove of the ordinary siphon-pipe pattern, placed in an upper chamber above the furnace, and heated by the waste flame. The temperature at East Middlebury is said to be from 280° to 320°. The use of hot blast is attended with a considerable saving, both of time and fuel, 240 bushels of charcoal being sufficient to produce a ton of bloom with hot, while 300 are required with cold blast. The weight of the charcoal may be estimated at from 16 to 18 lbs. per bushel.

The working of the furnace is conducted in the following manner :—The fire having been made up and the furnace heaped with charcoal, the ore, in a coarsely pulverised form, is scattered at short intervals over the top of the burning fuel, and in its passage downwards is reduced to the metallic state, the grains agglomerating to an irregular mass or loup at the bottom, while the earthy matters form a liquid slag or cinder, which is drawn off from time to time through the openings in the front plate. Fresh ore and coal are continually added, until at the end of two or three hours a sufficiently large loup is formed. This is then lifted before the twyer to get a good welding heat, and shingled to a bloom under the hammer, the reheating of which is usually effected in the same fire.

In the larger-sized furnaces a loup of 300 lbs. is produced every three hours, making the produce per day of 24 hours 2,400 lbs. of blooms; in some cases it is said 1,500 lbs., or even more, are produced in 12 hours.

The essential difference between the Catalan and the American forge consists in the method of charging. In the former the greater part of the charge of ore, in comparatively large lumps, is placed at the commencement of the operation on the sloping wall of the hearth opposite the twyer, only the small ore or *greillade* being added subsequently. In the American or German method, on the contrary, the whole of the ore is reduced to a fine state of division, and is added by small portions—a plan which dispenses with the charging of the furnace after each operation, and permits of a continuous system of working.

In order further to economise the waste heat, the plan usually adopted in the Franche-Comté fire, of passing the flame and gases from two hearths into a chamber, which serves for the reheating of the blooms when it is required to draw them out into bars, a set of small blast pipes, placed just above the forge, serves to heat a portion of air, which is led into the chamber to burn any carbonic oxide gas that may have escaped. The gases from the reheating chamber are afterwards employed to heat the principal blast of the forge in the usual manner.

At Ausable, in the State of New York, the ores employed are dressed so as to yield about 50 per cent. of iron—two tons being required to make one ton of blooms; while at the New Russia forges, where a nearly pure magnetite is smelted, three tons of dressed ore are stated to yield two tons of blooms. The loss at this rate would not be more than about 5½ per cent. on the theoretical contents of the ore—a result which could scarcely be obtained by any other method.

At Moisie, in Quebec, where titaniferous black sand is treated, the results obtained are not so favourable, owing to the more refractory character of the ore. The twyer is laid nearly horizontal, as it was found that the strong inclination used with coarser ores could not be advantageously used with the fine sands. A less dense blast is also used, the average working pressure being about 1 lb. to the square inch. Each hearth yields eight loups, or about 15 cwt., in the day of 24 hours; the consumption of charcoal being at the rate of 466 bushels to the ton of blooms. This charcoal is chiefly produced from small and light wood, such as spruce, fir, and birch, the weight being only 15 lbs. to the bushel, about 62½ cwts. being consumed to make a ton of iron.

This very unfavourable result is due to the imperfectly cleaned state in which the ore is smelted—the quartz, but more especially the titanic acid, using up a large portion of the protoxide of iron, in order to form a slag. The amount of titanic acid in the slags is in some cases as high as 34 per cent., and the iron from 40 to 52 per cent. By the use of magnetic machines for separating the ore before treating it in the furnace, it would be possible to remove the non-magnetic and more highly titaniferous part, which is practically worthless, leaving a comparatively pure magnetite, which could be much more advantageously smelted.

The quality of the iron produced in the bloomary fire at Moisie is said to be very superior, as the result of experiments made upon it in England show that it possesses a tensile strength equal, or superior, to that of the best Yorkshire iron, and works easily both cold and hot. This excellence is to be attributed to the almost perfect freedom of the magnetic sand from sulphur and phosphorus. A sample taken from a bloom when examined gave only ·0094 per cent. of sulphur, and 0·184 per cent. of phosphorus, and no trace of titanium could be found.

CHAPTER XIII.

REFINING, OR CONVERSION OF GREY INTO WHITE CAST IRON.

When grey cast iron is melted in an oxidising atmosphere, the silicon in combination is oxidised to silica, and separates as a silicate of protoxide of iron, a portion of the iron being oxidised at the same time.

If the metal be run into moulds and suddenly cooled, the whole of the carbon enters into combination, with the production of a peculiar silvery-white metal, which is analogous in composition to that smelted from pure ores at a low temperature with a high burden of materials. The same result may be obtained by stripping thin plates or discs from the bath of molten metal by throwing water on to its surface, and subjecting them to a red heat in contact with air for several hours, a process followed in parts of Germany, and known as roasting (*braten*). The more usual method, however, consists in melting the metal with coke or charcoal in a small hearth of rectangular section, with one or more inclined twyers, through which cold blast air is made to impinge upon the surface of the melted metal. This process is known as refining, and the furnace, or hearth, as the refinery. The object of the operation is to reduce the fluidity of the melted metal, as well as to diminish the amount of silicon, or slag-making material, whereby the subsequent treatment in the puddling furnace is facilitated. The term "running out fire," which applies to the refinery, has reference to the use of a long cast-iron trough, forming a chill-mould for the metal, which is run out of the hearth as soon as the refining has been carried to the proper point.

The general arrangements of a refinery fire are shown in Figs. 23, 24, which, together with the accompanying description, have been taken from Tomlinson's "Cyclopædia."

The hearth H, Figs. 23, 24, is 2½ feet wide, and 3½ feet long. It is formed by the junction of four cast-iron troughs, I, through which a stream of cold water is made to circulate, to prevent them from being fused by the heat. The bottom of the crucible is of grit-stone or argillaceous sand, and is slightly inclined in the direction of the tapping-hole, *o*. The air, which is usually supplied by the same engine that blows the

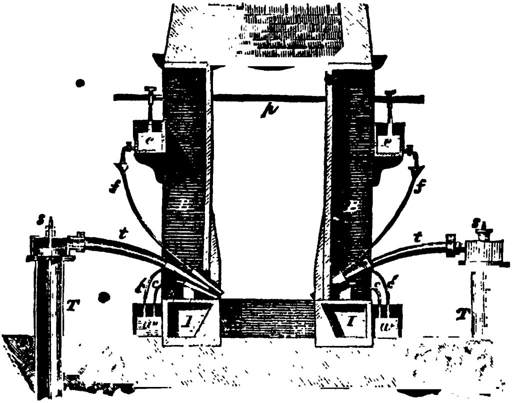


Fig. 23.—The refinery.

blast furnaces, enters the hearth through the six twyers,

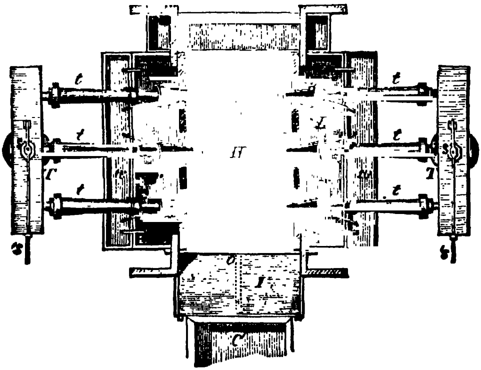


Fig. 24.—Plan of refinery.

t, which are inclined at an angle of from 25° to 30°, and so arranged that the blast from each may be directed towards the face of the opposite side of the furnace, not in opposition to the opposite twyer. The twyers are furnished with double casings, through which cold water is constantly running. A supply of water is brought by a pipe *p* into the reservoirs *e*, whence it passes to the twyers, through the pipes *f*, and escapes through the tubes *c′* into the tanks *w*, into which the water from the iron troughs flows by the syphon tubes *c*. A furnace of this kind consumes about 400 cubic feet of air per minute. This is supplied by the pipes T, which are furnished with screw-valves at *s* for regulating the supply. Above the hearth is a chimney 16 to 18 feet high, supported by four cast-iron columns, so as to allow free access to the fire on all sides. The tapping hole *o* is placed in one of the shorter sides of the hearth, and by it the melted metal and the slag flow out into the mould C, where the metal is cooled by quenching with water.

In Wales the hearth of the refinery is about 4 feet square, and from 15 to 18 inches deep, with two or three twyers on either side. In Yorkshire the twyers usually alternate with each other on opposite sides, two being placed on one side and three on the other. The hearth bottom is made of sandstone or fire-brick. Sometimes the metal is run in directly from the blast furnace, but more usually the charge of selected pigs is melted down with coke in the hearth. In the latter case, the metal in the form of pigs and scrap is placed in alternate layers with coke, upon a bed of ignited fuel, at the bottom of the hearth, and the blast is supplied at a pressure of from 1½ to 2½ lbs., according to the combustibility of the coke. In from two to two and a half hours' time, the charge, weighing two tons, is melted. Fresh fuel is then added, and the blowing is continued for half an hour, until the metal is sufficiently decarburised. The fluid contents of the hearth, metal and slag, are then tapped off together into shallow cast-iron troughs placed in front, which are kept cool with water. The usual dimensions of the moulds are about 10 feet long, 3½ feet broad, and 6 or 8 inches deep. The separation of the slag is facilitated by throwing water upon the surface. When the metal is run directly from the refinery into the puddling furnace, the slag must first be removed.

When freshly-fractured fine metal is of a silvery-white colour, the lower part is compact, with a radiated or parallel columnar structure, the top being dull and cellular. The usual thickness of the plate of metal is about 3 inches to a depth of 1 inch or 1½ inch. From three to four hours are necessary to work off one charge, according to whether the iron is grey or white, the former taking the longer time. The consumption of coke is about 2½ cwt. per ton of pig iron operated upon. When taken directly from the blast furnace, 22·3 cwt. of common forge, or 22·1 cwt. of good grey cast iron, are required to produce one ton of fine metal. In the melting finery the quantities are about 20 per cent. more. The slag produced amounts to about 3 cwt., and contains from 50 to 60 per cent. of iron.

The loss of weight in refining hot blast pig iron, from its being more highly charged with foreign matters, is greater than is experienced in the treatment of that smelted by cold blast. The metal produced from blackband is especially difficult of treatment, owing to its comparatively ready fusibility, which renders it necessary to continue the blowing for a long time, with a corresponding increase of waste, 24 cwt. being required to make a ton of fine metal. The twyers are usually inclined at an angle of 38 , and from 1½ to 1¾ inches in diameter: 94,000 cubic feet of blast are given per ton when the metal is run in from the blast furnace, but when melted in the hearth 136,000 feet are required with white, and 153,000 feet with grey cast iron. The weekly production of a refinery is from 150 to 160 tons in the former, and from 80 to 100 tons in the latter case. About 16-horse power is required to furnish the blast. In France and Belgium, the consumption of coke is about 30 per cent. by weight of that of the pig iron refined. A hearth with six twyers produces 130 tons, and one with four twyers only 90 tons of fine metal per week.

The process of refining may be accelerated in the same manner as is usual in all methods of making malleable from cast iron, namely, by the addition of solid oxygen in the form of rich basic silicates of protoxide of iron, such as the slags from reheating furnaces, or forge scale, which consists chiefly of magnetic oxide of iron. By the use of these fluxes the action of the blast is supplemented, and the carbon of the cast iron is employed in the reduction of a portion of the oxides of iron to the metallic state, with a diminution of the loss of iron. The saving is, however, more apparent than real, as the essential point of the process is the removal of combined silicon, and this can only be effected by its oxidation to silica, with the simultaneous production of tribasic silicate of protoxide of iron; and whether this be done at the expense of the metal under treatment, or of the iron reduced by the secondary reaction from the rich slags added, is of very little consequence, as the latter owe their origin to exactly the same kind of destructive action upon metal previously operated upon.

Lime may be beneficially employed as a flux for the removal of sulphur, especially that contained in the fuel, but its use is restricted by the fact of its giving a pasty and comparatively infusible slag, except when present in very moderate quantity. Manganese works in a similar manner, but more efficaciously, and, as has been already stated in considering its action in the blast furnace, increases the fluidity of the slag.

In Silesia, the conversion of grey into white cast iron is performed in the reverberatory furnace, heated by gas instead of solid fuel. The construction is very similar to that of the ordinary founder's reverberatory furnace. The bed is made of sand set in an iron frame with hollow sides, which is kept cool by a current of air passing through it. The fireplace is replaced by a vertical shaft of rectangular section, about 5 feet high, which is filled with coal. Air at a pressure of about 4 lbs. per square inch is admitted through a passage close to the level of the floor, and is distributed to the fuel through a number of small parallel jets attached to a wrought-iron pipe. The gas produced by the imperfect combustion of the coal is burnt at the top of the shaft, which corresponds in position to the firebridge of an ordinary furnace, by a fresh supply of air introduced through a long narrow mouth-piece, extending across the entire breadth of the hearth, and inclined at an angle of about 30°, so that the flame is urged downwards in a thin sheet upon the surface of the metal. The charge, weighing two tons, takes about three hours to run down, during which time the draught is regulated by the stack alone. A small quantity of limestone is then added, in order to convert the infusible dross on the surface of the metal into slag, after which the blowing proper commences, by means of a further supply of air from two twyers placed on opposite sides of the hearth, which impinge obliquely on the molten metal, producing a movement of rapid rotation. The duration of the operation varies from two and a half to five hours, according to the quality of metal required, the longer time giving a perfectly white iron. The loss is only about 5 per cent., owing to the use of limestone flux. According to Abel, the change is chiefly confined to the elimination of carbon and silicon, as in the common refinery, sulphur and phosphorus, when present in the pig iron, being but slightly affected. The following are the relative proportions of these elements before and after refining :—

	Pig iron.	Refined iron.
Silicon	4·66	0·62
Phosphorus	0·56	0·50
Sulphur	0·04	0·03

The amount of silicon remaining is considerable; but this is probably due to the use of limestone instead of fluxes containing oxides of iron, the object being merely the production of refined iron for foundry mixtures, and not for conversion into malleable iron.

In Parry's method of refining, the cast iron operated upon is run directly from the blast furnace into the hearth of a reverberatory furnace, heated by a coal fire in the usual way. The blowing is effected partly by air and partly by a jet of steam, introduced through a twyer inclined at an angle of 45°. The weight of the charge is 35 cwt. of pig iron, and about 7 cwt. of forge cinders. A ton of grey iron may be refined by steam in half an hour. The jet is three-eighths of an inch in diameter, with a pressure of from 30 to 40 lbs., and superheated to 300°—350°, by keeping the orifice about 2 or 3 inches above the surface of the iron. Of course, water twyers must be used, as in the case of the hot blast furnace. The consumption of coal is said to be at the rate of 2 cwt. per ton of refined metal produced. This is chiefly expended in replacing the heat absorbed by the decomposition of the steam, which produces great local cooling, so that, if the supply be too great, as compared with that of the air blast, the iron may be cooled below its melting point.

The following analyses of metal and slags, obtained in this process at Ebbw Vale, in South Wales, are by Noad:—

	Pig iron used.	Refined metal.
Carbon, graphitic	2·40	0·30
Silicon	2·68	0·32
Slag	0·68	—
Sulphur	0·22	0·18
Phosphorus	0·13	0·09
Manganese	0·36	0·24
	Forge cinder added.	Cinder run out.
Sulphur	1·34	0·16
Phosphoric acid	2·06	0·13

The slags obtained are therefore as pure, in respect to sulphur and phosphorus, as the ordinary run of Welsh iron ores.

The process introduced by Mr. Heaton, of Langley Mill Iron Works, near Nottingham, may be conveniently noticed at this point, as, though intended for the production of steel, it is essentially a modification of the refinery, with this difference, that nitrate of soda is employed as an oxidising agent, instead of a blast of air.

The converter is a wrought-iron cylindrical cupola lined with refractory material, having a movable bottom, which when in use is kept in place by iron clamps. The lower part of the bottom is filled with nitrate of soda, in the proportion of 2 cwt. to the ton of iron treated. Sometimes, but not always, an addition of about 25 lbs. of siliceous sand is made. This charge is covered over by a closely-fitting perforated plate of cast iron, in order to prevent it from floating up through the molten metal without decomposition. When the bottom is adjusted, molten cast iron is introduced through the charging-hole at the top. The effect of the nitrate upon the oxidisable matter in the iron is but slight for about five or six minutes, until the covering plate is melted, when a violent ebullition takes place, and a bright yellow flame issues from the top of the chimney for about a minute and a half more, when the action rapidly subsides. The bottom of the converter, with its contents, is then detached, and removed by a truck, placed below it. The product of this operation, which is called *crude steel*, is not sufficiently fluid to be run out into moulds when only small charges of 12 cwt. or 15 cwt. are operated upon. The contents of the converter are therefore turned out upon the floor, and are then broken up into lumps of convenient size for further treatment.

This consists of a series of pilings and reheatings in an ordinary balling furnace, after being shingled into blooms or cakes of crude steel, when iron bars or plates are required; or the cakes may be melted in crucibles in the ordinary way to form crucible cast steel.

Several investigations of the nature of the changes taking place in this process have been published, the first being that of the late Dr. W. A. Miller, F.R.S., who examined specimens taken at the Langley Mill Works in 1868, and has given the following analyses:—

	A.	B.	C.
Carbon	2·830	1·800	0·993
Silicon, with a little titanium .	2·950	0·266	0·149
Sulphur	0·113	0·018	trace.
Phosphorus	1·455	0·298	0·292
Arsenic	0·011	0·039	0·024
Manganese	0·318	0·090	0·088
Calcium	,,	0·319	0·310
Sodium	,,	0·144	trace.
Iron (by difference) . . .	92·293	97·026	98·144
	100·	100·	100·

A. cupola pig; B. crude steel; C. steel-iron.

The nature of the above products is not apparent from the analyses, as the terms do not seem to be used in the ordinary sense. Thus, the so-called steel iron contains as much carbon as a very strong steel. The amount of phosphorus retained, though said to be insufficient to injure the quality of the iron, is about four times as much as that in the best Yorkshire iron, or from ten to fifteen times as much as in Swedish Bessemer steel.

Gruner, who examined Heaton's process for the purpose of testing its applicability to the pig iron smelted in the Moselle valley, states that the iron and steel produced were capable of resisting a high tensional strain, but that the elongation before fracture was very small, which shows the metal to be hard and deficient in body, the defect being most marked in the hardest steel, the softer steel and homogeneous iron being comparable to ordinary Bessemer steel, only somewhat harder.

Grey pig iron, rich in silicon, is less readily purified than white, as the silicon is oxidised before the phosphorus. Even in the most favourable case, the removal of the latter element is very incompletely performed, the refined metal retaining about one-third of the quantity contained in the pig-iron. Gruner therefore suggests, in order to prevent a great waste of nitrate of soda, the propriety of removing the bulk of the silicon and phosphorus by preliminary treatment in an ordinary Welch or reverberatory refinery, the fine metal being then run direct into the Heaton converter for a further purification with the nitrate. It is doubtful, however, whether there would be any advantage in adopting such a complicated method of treatment, and the revival of the use of the refinery for ordinary forges would be a decidedly retrograde step.

The following analyses, illustrating the changes that take place both in the ordinary refinery and in the Heaton process, are by Mr. G. J. Snelus, of Dowlais:—

	I.	II.	III.	IV.	V.	VI.
Carbon, graphitic .	0·800	2·428	2·360	2·570	2·061	1·098
" combined .	1·797		0·446			
Silicon . . .	1·908	0·128	2·006	1·959	0·014	trace
Sulphur . . .	0·553	0·144	0·034	trace	trace	trace
Phosphorus . .	0·886	0·815	0·446	0·558	0·489	[illegible]
Manganese . .	0·050	trace	0·648	0·885	0·064	0·072

I. is an ordinary white forge pig iron; II. the refined metal made from it; III. and IV. are two different brands of pig, mixed together to form the charge in the Heaton converter; V. is hard, and VI. is soft crude metal from the converter.

It will be seen, by comparison of No. II. with Nos. V. and VI., that the most marked effect of the nitrate is the almost entire removal of the silicon, which is to be attributed to the fluxing effect of the alkaline base.

Henderson's method for the production of steel and malleable iron from inferior brands of pig, depends upon the joint use of titanic acid and fluor spar, whereby silicon, sulphur, and phosphorus are said to be wholly, or in part, removed.

The first operation consists in the production of titaniferous cast iron of the following composition, by fusing 1 ton of Cleveland pig with 7 cwt. of Norwegian titaniferous iron ore:—

Carbon	1·298
Silicon	1·811
Titanium	1·255
Phosphorus	0·460
Sulphur	0·362

The metal from the first operation is charged upon a bed of powdered fluor spar, spread uniformly over the bottom of a puddling furnace, and when melted, the fining takes place by the reaction of the fluoride upon the silicon and other foreign matters in the charge, so that the operation is completely performed under the slag, without stirring or manual labour, other than that required for balling up the finished iron. The composition of a sample of malleable iron produced in this way is given as follows:—

Titanium	0·022
Carbon	trace
Silicon	none
Phosphorus	0·140
Sulphur	0·062

This is said to be a good malleable iron, although containing no carbon, which seems improbable.

A simpler modification of the process, consists in using the titaniferous ore and fluor spar together in the puddling furnace at one operation. These are taken in the proportion of 48 lbs. of the latter to 118 lbs. of the former. They should be ground to a fine powder, and charged evenly over the bottom of the furnace. 475 lbs. of pig iron are then placed on the bed so prepared, and the furnace closed, so as to exclude air as completely as possible for about an hour and ten minutes, the fire being urged to obtain the highest possible temperature. After the metal has been in the furnace for this period, samples should be taken at intervals of five minutes, in order to judge of the amount of change produced. It is essential not to stir or work the metal during the conversion, as the fluor spar and titaniferous iron ore become viscid by the heat of the furnace as soon as the cast iron melts, and if left alone, will remain on the bottom of the furnace until decomposed. The time occupied in the conversion of the steel, from the charging of the pig iron, is about an hour and a half, which may be shortened to thirty or forty minutes by adopting the method of previously refining the iron, which removes the silica and the greater part of the phosphorus.

Sherman's refining process, which has been recently introduced on an experimental scale, both in America and this country, is based upon the use of iodine or iodide of potassium in the puddling furnace, very small doses being said to produce great effects in the removal of phosphorus and sulphur. Few of the results hitherto published appear to justify this conclusion, and in the absence of any good analytical investigation of the subject, it is difficult to accept the process as being any great advance towards the solution of the problem of making good steel from inferior iron, which exercises a strange fascination over the minds of a large class of inventors.

CHAPTER XIV.

PRODUCTION OF WROUGHT IRON IN OPEN FIRES.

THE numerous processes employed in the production of malleable from cast iron are divisible into two classes, according to the nature of the furnaces employed, namely, *open-fire or hearth fineries*, where the pig iron is melted and decarburised in a shallow hearth before the blast of an inclined twyer, and reverberatory or *puddling fineries*, where the same operation is performed on the bed of a reverberatory furnace. The reactions going on during the process are similar in either case. The carbon, if it exist originally as graphite, first passes into the combined state, and is then converted into carbonic oxide either by the oxygen of the blast, directly, or indirectly by the action of protoxide, peroxide, or magnetic oxide of iron dissolved in the slag. These oxidising agents may be derived from the pig iron under treatment, which is always oxidised to a certain extent under the influence of the blast during the melting, or they may be added in the form of red hematite, forge scale, or slags containing protoxide of iron in large quantity, such as are produced towards the end of the finery process itself. When these latter substances are used, it is necessary to bring them into intimate contact with the metal by mixing them well together when the charge is in a semi-fluid condition.

White cast iron is more suitable for conversion into malleable iron than grey, as it does not, when raised to a high temperature, pass immediately from the solid to the liquid state, but assumes, when near its melting point, an intermediate or pasty condition, favourable to the more effectual action of the air or other agents employed in the removal of the combined carbon. Grey metal, on the other hand, though requiring a higher temperature for fusion, becomes very liquid, and in a deep hearth sinks below the level of the blast, and becoming covered with a coating of slag, is completely protected against the action of the air, unless it is brought under the influence of the blast by stirring or lifting with an iron bar, an operation which involves great labour, and delays the fining. This gives rise to an increased expenditure of fuel and waste of iron. No sensible amount of decarburisation takes place until the whole of the graphitic carbon has entered into combination with the iron, or what amounts to the same thing, until the metal has passed from the grey to the white state: this conversion is an essential preliminary in all finery processes where the air is introduced above the surface of the melted metal.

In Bessemer's process, which consists essentially in forcing air through molten pig iron from below, exactly the reverse conditions prevail, grey pig iron being exclusively used on account of its fluidity, and probably from the uncombined carbon being readily consumed, owing to the extremely high temperature at command. As the removal of the carbon is effected by air alone, the plastic quality of white iron is not requisite, and would interfere with the free passage of the blast. This process, although of great importance in steel manufacture, is not directly used in the production of malleable iron; it will not, therefore, be necessary to consider it further in this place, it being only mentioned to show the great practical differences in the action of a blast of air upon molten cast iron, according to whether it be made to act from above or below the metal.

Grey pig iron is often subjected, as a first step in the process of making malleable iron, to a preliminary oxidising fusion in the refinery or running-out fire, which is a rectangular hearth with one or more strongly-inclined twyers. The molten metal, after a certain amount of blowing, which deprives it of its graphitic carbon and silicon, is converted into *fine* or *refined metal*, and may either be run directly into the finery furnace or hearth, cast in chilled moulds, or stripped in thin flat discs by throwing water upon its surface when melted. The product is a white brittle metal, resembling the cellular or flowery white pig iron obtained in charcoal furnaces from a heavy burden of rich ores; it differs from common or white cinder pig iron in being almost free from silicon.

The application of the terms *finery* and *refinery* is somewhat contradictory: the latter, though apparently of larger signification than the former, refers only to a single step in the process of making malleable iron, namely, the conversion of grey into white cast iron. In Germany, this operation is distinguished as *whitening* (weiss machen), and the finery or conversion proper of cast into malleable iron as *freshening* (frischen). The same term is applied to the reduction of metallic lead from litharge, an operation known in England as *reviving*. In former times hearth fineries were usually called *bloomeries*—a term having reference to the form of the product, which was called a bloom or lump. The reheating or welding fires were called *chaferies*.

The methods of making malleable iron depending upon the use of open fires or hearth fineries, though great interest from their antiquity and comparative simplicity, are gradually diminishing in importance, owing to the more general use of the reverberatory or puddling process, which can be advantageously employed with fuel and materials of a lower quality, and also requires less skill in manipulation, owing to the more extensive use of machinery in the elaboration of the finished product.

In a general way, the working of a hearth finery may be described as follows: the charge of pig iron, usually in the form of broad thin slabs, is introduced into a shallow rectangular hearth, whose sides and bottom are formed of cast-iron plates, which are protected against the action of the fire by a lining or brasque of charcoal dust. The fuel employed is charcoal, the fire being urged by a blast of cold, or sometimes heated, air, introduced through an inclined twyer placed on one of the sides close to the top of the hearth. The fusion of the metal is allowed to take place very gradually, so that it may be exposed as fully as possible to the oxidising influence of the blast by falling in single drops through the entire height or depth of the hearth. By this means the silicon is converted into silica, and together with any sand adhering to the surface of the pig, combines with protoxide of iron, produced at the same time, forming a fusible silicate of protoxide of iron or slag, which, being specifically lighter than the molten metal, swims above it. As the oxidation of the iron continues, the slag becomes more basic by the addition of magnetic oxide in indefinite proportions, which, when the whole mass is well liquefied, reacts upon the carbon of the metal, producing malleable iron and carbonic oxide. Owing to the intensely oxidising atmosphere prevailing in the hearth, the production of the silicate goes on much more rapidly than its reduction by combined carbon, so that the volume of slag increases to such an extent as to form a coating sufficient to protect the metal from the action of the blast. It therefore becomes necessary to break up the iron, that is, to lift the imperfectly-refined masses from the bottom of the hearth to the twyer, in order to subject them afresh to the joint influences of the blast and slag as often as may be necessary, until the carbon is almost entirely removed. With the progressive decarburisation, the fusibility of the mass diminishes, and ultimately a spongy, slightly coherent mass or *ball* of malleable iron is obtained, which, when removed from the hearth, is at a strong white heat, and therefore susceptible of being welded, and is immediately reduced to a rough, prismatic lump, called a *bloom*, or a slab, by the blows of a heavy hammer moved by steam or water power. The bloom is drawn out into a finished bar under the same or a lighter hammer, after reheating either on the same hearth during the melting down of the next charge, or in a fire or furnace of special construction.

The simple operation sketched out in the preceding paragraph is susceptible of numerous modifications. More than a dozen so-called finery methods have been described by Tunner as in use at the present day: they are for the most part confined to the continent of Europe. As may be imagined, the differences between them are in many cases extremely small, and turn rather upon details of manipulation than actual diversity in principle or construction of apparatus. The most remarkable point in connection with this subject is the great diversity of terms used in different districts, almost every locality having a complete set of its own, which, as a general rule, are only current within a limited area. The reason of this becomes apparent, when we consider that iron-making in the olden times was carried on in remote districts, where wood and water power could be easily obtained, as, for instance, in the valleys on the flanks of great mountain ranges of Central Europe, the small size and weight of the finished bars, &c., requiring only the simplest means for conveyance to market, such as could be found in pack animals, without even the necessity for roads passable for wheeled carriages. In this way each district may have developed its own process without knowledge of what was doing in the same matter elsewhere; and the local experience would be incorporated as a technical language, whose use would be confined to a small class of workmen on the spot.

The introduction of the puddling furnace, and the necessity of good roads for the economic transport of materials to and from the forge, have had the effect of bringing iron manufacture from the seclusion of the valley to the high road, and as a consequence of the change, an almost exact uniformity of language has been introduced, all the terms connected with the puddling furnace and rolling mill originating in England having been adopted in foreign countries, in many cases even without alteration, or at most have been literally translated.

The gradually-increasing scarcity and consequent rise in the price of wood, together with the increase of facilities for conveyance of coal to works at a distance, have led to the abandonment of the open-fire method of finery in many districts, as, for instance, in the Eifel and Walloon countries; and even in Scandinavia, although carried to a high degree of perfection, it is giving way before the puddling and other modern processes, which are susceptible of greater economy in working.

The numerous methods of hearth finery which have been alluded to above may be classified under three heads, according to the number of times that the metal requires to be broken up or lifted, from the melting down of the charge to the preparation of the ball for hammering; that is, as single, double, or manifold running-down processes (*einmal, zweimal*, or *mehrmal schmelzerei*). The distinction between these is in great part due to the number of furnaces employed. Thus in the last, of which the old German or Walloon forge may be taken as the type, the three operations of refining, or conversion of grey into white metal, lifting and fining proper, or breaking up, and the final balling, are performed in the same hearth; in the second, or double process, the metal is run into the finery or blooming hearth from a melting finery or running-out fire; and in the first, or single process, which is used in Styria with white pig iron approximating in composition to refined metal, the removal of the combined carbon is effected chiefly by special oxidising agents without much working before the twyer: the product is a steely iron, whose excess of carbon is afterwards removed by subjecting the bloom to several welding heats.

A further distinction of these processes is founded upon the method adopted in working the iron as it fines, or, as is said in English, *comes to nature*. Thus, with metal of a good quality, the whole charge may be allowed to come up together by lifting and working it in one mass before the twyer, whereas with a lower quality the particles of iron, instead of being allowed to coalesce as they form, are broken up into several masses, which, after having being refined separately, are worked into one ball as before, or each one may be forged alone into a bloom of smaller size.

The slags produced in the earlier part of the process, as well as those of the refinery, as a rule approximate in composition to tribasic silicates of protoxide of iron, with variable quantities of manganese and earthy bases, according to the character of the pig iron under treatment. Towards the end they become more basic, and at last a difficultly-fusible substance, containing from 75 to 85 per cent. of protoxide of iron, remains in the hearth. This, together with the more fluid, but also basic slag expressed from the ball by hammering, is employed as a decarburising agent.

The construction of hearth fineries is subject to a certain amount of modification in different localities. In the simplest, or old German forge, already alluded to, the top of the hearth is near the ground level, and the flame escapes directly into an open hood, like that of an ordinary smithy fire; but in the more improved forms adopted in the Franche Comté and Lancashire forges used in Sweden, the hearth proper is covered with a cylindrical roof, and communicates by a lateral flue with a brick chimney. A portion of the waste heat of the flame is economised by causing it to pass over the pig iron forming the next charge, which is placed in the flue, and is raised to a strong heat, and partly oxidised. It is found that this preliminary heating causes a considerable saving, both of fuel and time, in the subsequent process of fining, being somewhat similar in effect to the refinery. The flame is also used in heating the blast, for which purpose a coil of cast-iron pipes is placed, either above the hearth, or between it and the base of the chimney stack.

The Bergamask forge process, used in the neighbourhood of Bergamo, Brescia, and Lecco, in Northern

Italy, differs from those already noticed by the large use made of oxidising substances, and may be regarded as bearing the same relation to them that the modern or boiling system of puddling does to the original or dry process. The charge of pig iron, when melted and cleared from the supernatant cinder, is mixed with rich forge slag, which reduces it to a pasty consistency, removed from the hearth, and cooled with water. The partially-refined product is then exposed in small portions in the same hearth, after making up the fire, to a low heat, sufficient to agglutinate the iron and cinder into a cake, which is again taken out and cooled. In the third stage, each of these cakes, or *cotizzi*, is refined in the ordinary way, but with the addition of a further quantity of rich slag or cinder.

Owing to the intermittent nature of the process, the hearth having to be twice heated and cooled in each operation, the consumption of fuel is considerable, being nearly two and a half times the weight of the finished bars. The loss of iron estimated on the pig is 4½ per cent., or, taking into account that contained in the cinder added, from 18 to 19 per cent. The charge weighs 5 cwt., and produces in one operation, lasting eighteen hours, about eighteen finished bars, weighing from 25 to 30 lbs. each.

The pig iron employed is smelted from manganesiferous spathic ores occurring in the triassic rocks near the lake of Como, in stratified masses, of which five are known, the greatest individual thickness of 27 feet being observed in the bed of La Manina, in the valley of Dezzo.

In South Wales, a superior quality of iron, adapted for rolling into thin sheets for use in the manufacture of tin plates, is made in the charcoal finery. The metal treated is usually of a good class, such as that smelted with anthracite or coke; in the latter case, with cold blast from Welsh mine or hematite pig. The charge, weighing generally from 5 to 6 cwt., is first heated in a small coke refinery about 18 inches square, with two twyers, and, after the requisite amount of blowing, is run off by an inclined gutter into the charcoal fineries, of which there are two, placed in front of and a little below the running-out fire. These hearths are made of cast-iron plates; the bottoms are hollow, and cooled by a current of air. Three of the sides are vertical; the fourth, or working side, is slightly inclined upwards and outwards. The charge of fine metal is equally divided between the two hearths, which are each blown by a single twyer. Although cold blast is used, the nozzle is protected by water twyers, both in the refinery and charcoal hearths. The fining appears to be done dry, that is, without the addition of slag or scale, by continual breaking up and raising the iron with a pointed bar; the slag, or cinder, is tapped off two or three times during the operation, which lasts from one hour to one and a quarter. The whole of the charge is worked into a single ball, weighing somewhat less than 2 cwt., which is shingled and drawn under a lever hammer to a long bar, about 1½ or 2 inches thick, and then broken into pieces, called *stamps*, weighing about ¼ cwt. each, by nicking the bar half through, and striking the weakened part with a sledge hammer. This method of breaking up the bar affords a ready means of selecting the iron by the appearance of the fracture, only such portions as present a fine uniform crystalline grain being used in the formation of the pile from which the finished sheet is made. A similar process of stamping and selection of rough bars is in use in those forges of the West Riding of Yorkshire that are noted for the high quality of their malleable iron.

The reheating or welding of the stamps is effected in a special furnace, known as the *hollow fire*, intermediate in character between the old chafery and the modern reheating furnace. It consists of a deep rectangular hearth roofed over at the top. The upper part forms a chamber, in which the piles are reheated. The lower part of the hearth is filled with coke, which is burnt by a blast of air introduced by an inclined twyer, near the top of the fuel, in the ordinary way. The piles consist of fragments of the broken bars, or stamps, obtained in the preceding operation, and are supported on a flat plate or staff in the upper part of the fire, clear of the top of the fuel, but fully exposed to the flame. If the blast is introduced at a lower point, so that the air has to traverse a certain thickness of ignited fuel, the conditions of combustion become similar to those of a gas generator, and the furnace approximates to a gas reheating furnace with the top blast omitted. A portion of the waste flame is economised by the use of a second heating chamber, where the pile receives a preliminary heating before it is brought up to the welding temperature.

In Sweden, three principal methods of charcoal finery are in use: the German, or rather Walloon, the Franche Comté, and the Lancashire processes. The first of these is confined to those forges that produce the Dannemora steel irons. The hearth is not covered, and the fining, which takes place in a bath of slag, is much accelerated by almost continuous breaking up and stirring of the molten metal. The bloom is of small size, weighing only about 100 lbs., and is produced in from twenty-five to thirty minutes. The pig iron of a white or strongly-mottled character is not charged and melted down in one quantity, but is used in the form of slabs or bars from 15 to 18 feet long. Only the fore-end of the slab is exposed to the fire, so that the metal melts and runs down in drops before the blast like sealing-wax in the flame of a candle, the end, as it wastes, being kept in the same position by pushing forward. The bloom obtained from the previous heat is reheated for the first time in the fore-part of the hearth during the period of melting, being held with tongs in an inclined position: the subsequent heats, to the number of six or seven, required in drawing it out into a bar under the hammer, are effected in a separate fire. The consumption of charcoal is very large, being three times the weight of the bar iron produced; the loss of weight, or difference between the latter and the pig iron used, is from 20 to 25 per cent.

The Franche Comté and Lancashire processes are conducted in covered hearths with flues for heating up the charge of pig iron previous to melting, and stoves for the blast, which is raised to a temperature of about 100°; the pressure is from 1 lb. to 1¼ lb. The principal difference between them is that in the former the reheating of the bloom, which is cut into two pieces after shingling, is effected in the same fire, while in the Lancashire forge either a second hearth, or what is now more usually the case, a gas-welding furnace, is used for this purpose. The proportional yield is about the same in both cases, the weight of bar iron produced being about 15 per cent. less than that of the pig iron used. The consumption of charcoal is, under the most favourable conditions, about the same in either process, being one and a half times the weight of the finished bars, or only half as much as in the Walloon forge.

CHAPTER XV.

REVERBERATORY FINERY OR PUDDLING PROCESS.

THE use of the reverberatory furnace, instead of the open fire or hearth, in the conversion of cast into malleable iron, was introduced by Cort in 1784, and has now almost entirely superseded the older processes in those localities that are chiefly dependent upon mineral fuel. Even in wooded districts its use is becoming general, more especially since the introduction of gas furnaces, which are capable of being worked with fuel of inferior quality and heating power—such as wood, brown coal, peat, &c.—when converted into carbonic oxide, such substances being unfit for use in fineries where the heat is produced by combustion of the fuel in contact with the iron.

The reactions going on during the operation of puddling are substantially the same as those observed in hearth fineries, the decarburisation of the pig iron being effected by the joint action of a current of air produced by the draught of a chimney, instead of being blown in under pressure from a twyer, and oxidising fluxes, such as hematite, magnetic oxide of iron, forge scale, or the molten slag, a highly basic silicate of protoxide of iron.

According to the relative importance of the parts played by these agents, the process is divided into *dry* and *wet* puddling, the former being dependent mainly on the exposure of the metal to the action of the air, while in the latter, which is more generally known as the *pig-boiling* process, the slag and oxide of iron added are the most important oxidising agents.

As the charge of melted pig presents a larger surface for the same weight in the puddling furnace than is the case in the open fire, it forms a thinner layer, and therefore can be more readily brought into contact with the air; the operation of fining is more quickly performed; and the labour of lifting, &c., although very severe, is less so than in the hearth finery, especially in the treatment of grey iron. The conversion of the latter into white metal by a preliminary fusion in the refinery is, however, equally advantageous in either case.

The general details of the construction of the puddling furnace, are shown in the four figures (Fig. 25), A, B, C, and D. The fireplace is of rectangular form, built of fire-bricks, and divided from the hearth by a low wall or fire-bridge. The roof of the furnace is curved to a flat arch, and is generally made to slope at a small angle towards the flue. The whole of the brickwork is cased with side plates of cast iron, united by flanges and bolts, and bound together with wrought-iron tie-rods across the top. The bottom of the bed is formed of plates of cast iron, united by tenon joints, and supported upon dwarf pillars or standards of the same metal. The sides of the bed may be variously constructed, the differences being due to variations in the methods of artificial cooling adopted. In the furnace in question they are formed of hollow iron castings, united into a rectangular tube, through which a current of air circulates for the purpose of protecting the metal against the intense heat of the furnace. The bed is terminated at either end by a straight wall or bridge: that nearest the fireplace is called the *fire-bridge*, and the opposite one the *flue-bridge;* both are built of fire-brick, overlapping the top of the side frame, so as to form a recess for the reception of the refractory material used in lining or *fettling* the sides.

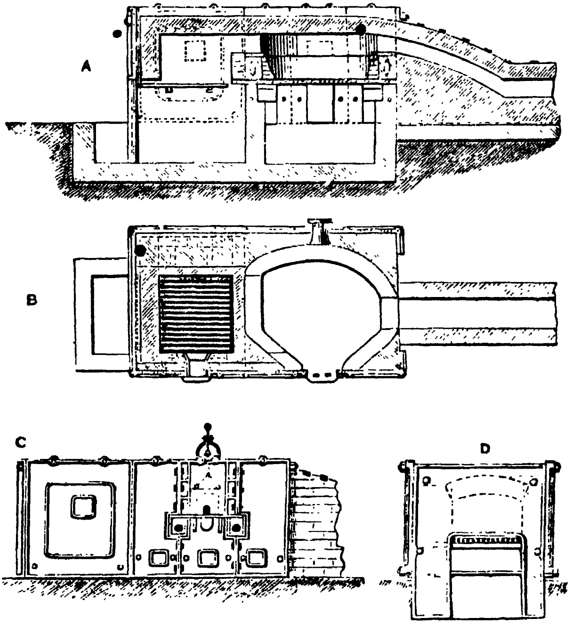


Fig. 25.—Puddling furnace.

A. Vertical section through the centre. B. Plan at level of bed. C. Side elevation. D. End elevation of fireplace.

The fire grate presents no peculiar features; it is made of plain wrought-iron bars placed horizontally, and carried at either end by transverse bearers. The depth of the fireplace varies with the nature of the fuel employed, being greatest with the least bituminous kinds of coal, in such cases, especially, where anthracite is burnt. A forced draught, produced by blowing air in below the grate, may be sometimes used to advantage. With peat, brown coal, or slack, inclined or step-grates are used, and by the combination of these accessories the indirect or gas furnace is produced. The best fuel for furnaces with ordinary grates is coal of a dry, non-caking quality, burning with a long flame, as free from sulphur as possible. The surface of the grate should be between one-half and one-third of that of the bed, which, taking the latter at 20 square feet, would give from 7 to 8 square feet. The amount of coal burnt is from 1½ to 2 cwt. per hour. The charging or fire-hole is 10 inches above the grate; it has no door, but is stopped with lumps of coal when the fire is lighted.

The flue is usually built with a slope towards the stack; the sectional area varies with the nature of the fuel, being about one-fifth of that of the grate for bituminous coal, and one-seventh for anthracite. Sometimes a second bed is placed behind the flue-bridge, upon which the pig iron destined for the following charge is subjected to a preliminary heating or roasting, by the flame passing over it on its way to the stack, in order to save time in the subsequent melting down. In like manner, when a blast is used above the grate, as in gas furnaces, it may be heated by means of a coil of horizontal **V**-shaped pipes of cast iron, placed on the lower part of the stack in the course of the flame, or by circulation through the hollow side frames.

The stack is usually from 30 to 50 feet high, and about 20 inches square, when it serves only a single furnace; but when the several flues are led into one, especially when a part of the heat is taken away by passing the flame under steam boilers, it is necessary to increase the height to 100 feet or more, in order to overcome the additional resistance. The walls of the stack are of fire-brick, with an outer casing of common brickwork, which is tapered in thickness, being set back in steps at two or different heights; the lower part is often supported on cast-iron columns or standards. The draught is regulated by a flat plate or damper at the top of the stack, attached to one arm of a lever, which can be raised or lowered by means of a chain attached to the opposite arm, which hangs nearly down to the ground level.

The working door, which is on the same side of the furnace as the fire-hole, is made of fire-clay slabs set in a cast-iron frame, and is suspended by a chain to a lever, carrying a counterbalance weight at the opposite end, in order that it may be readily lifted and lowered. It is only opened during the introduction of the charge and the removal of the puddled balls. A small rectangular or arched notch, called the *stopper hole*, is cut out of the edge for the introduction of the tool used in stirring or rabbling the bath of metal. The sill of the door is about 10 inches above the level of the bottom of the bed; below it is placed the tap-hole, through which the slag or *tap cinder* is withdrawn from the hearth. During the operation it is plugged up with sand in the usual way. A portion of the cinder also overflows the flue-bridge, and runs down the inclined surface of the flue to the bottom of the stack, where it is allowed to accumulate.

The side of the bed opposite to the working door is of a curved form, and is not directly accessible from the exterior in the ordinary or single furnace. In large forges it is usual to place two furnaces together in one block, back to back, with their working sides facing in opposite directions. The larger or double furnaces have working doors on both sides, so that two sets of puddlers can work at the same time, the weight of the charge being of course proportionately increased. In some few instances the beds have been made of such a size as to admit of working from four points simultaneously. It is doubtful, however, whether any advantage is to be got from the increased dimensions, as the saving of fuel and time claimed can only be realised by employing men of uniform skill, and capable of working off their heats in exactly the same time, otherwise a large loss of iron from burning is likely to ensue when one man brings out his heat before the other.

The working bed, or lining of the hearth, was formerly covered with sand, but is now usually made of refractory slags rich in oxides of iron, such as are obtained at the end of the process, the remains of old beds of a similar character, mill or hammer slag, or burnt scrap iron. In making a new bed, the cast-iron bottom-plate is covered with a layer of broken slags, 3 to 5 inches in thickness, which is then softened by long-continued heating, the surface being rendered smooth by working with a flat bar or paddle. When scrap iron is used, a quantity of about 4 cwt. is thrown into the furnace, which is then raised to a strong heat. The ball formed by the agglomeration of the particles of iron is worked down and spread as uniformly as possible over the entire bottom, care being taken to maintain a high temperature and oxidising atmosphere in the furnace during the operation. The thickness of the finished coating should not exceed 1¼ or 1½ inches.

Sometimes the bottom-plate is coated with a thin layer of fire-clay before the lining is introduced.

Grey pig iron should not be puddled alone upon a new bed; the first charges should consist of scrap iron or waste blooms, and refined metal in small quantities, until the refractory lining has become sufficiently consolidated, by continued oxidisation and a high temperature, to resist the solvent action of the silica produced from the oxidation of the silicon contained in the pig iron.

The side-plates of the hearth are lined or *fettled* in a similar manner with *bull-dog*, a mixture of peroxide of iron and silica, produced by roasting tap cinder, hematite, or magnetic iron ore. Limestone is sometimes used for this purpose, but does not appear to be generally advantageous, except as being less liable to waste, as it does not contribute to the decarburisation of the metal, and thickens the slag, and may prevent welding, producing a red short iron if mixed accidentally with the ball. The side linings are subject to considerable wear, and require to be repaired after each heat. For this purpose small heaps of fettling materials are placed by the side of each furnace. The larger holes are filled with lumps of crushed bull-dog, after which the surface is made smooth with *puddler's mine*, usually a soft red hematite, which is mixed to a paste with water. In Cleveland, besides the ordinary fettling materials, burnt pyrites, residues from the sulphuric acid works, called "Blue Billy," and finely-crushed Swedish magnetic iron ore, are in use.

Although the process of puddling is susceptible of considerable modification according to the nature of the pig metal employed, and that of the iron which it is desired to produce, it may be generally stated to include the following operations:—

1. Melting down of the charge, with or without previous heating.

2. Incorporation of oxidising fluxes with the charge at a low heat.

3. Elimination of carbon, by stirring the contents of the furnace at a high temperature.

4. Consolidation of the reduced iron to masses or balls fit for hammering.

The regulation of the temperature, and the amount of air passage through the furnace by the damper, is a point of considerable importance. The heat requires to be greatly raised towards the end, at the same time preventing an unnecessary influx of air, which would burn the iron to waste. In gas furnaces this is done by shutting off the top blast, so that the hearth is filled with an atmosphere of heated gas containing unconsumed carbonic oxide.

The following is a generalised description of the steps ordinarily pursued in puddling:—When the furnace is charged, the working door is shut and secured in position by iron wedges; sometimes the joint is luted with clay; the fire is made up after cleaning and pricking the grate; the fire-hole is stopped with lumps of coal and slack, in order that no air may enter the furnace except through the space between the grate bars during the period of melting down. In about a quarter of an hour the metal begins to soften; the puddler then introduces a bar or rabble through the opening in working door, and moves the unmelted lumps from the sides into the middle of the bed, in order to bring the whole more quickly into a state of uniform fluidity, the fire being increased at the same time for about four or five minutes. As soon as the metal is completely melted, it is rendered uniform by stirring, the temperature being lowered by partially closing the damper, until the surface of the bath is protected by a coating of slag against the direct action of the air. The amount of handling required in this part of the process depends upon the nature of the metal operated upon. With grey pig, which requires a higher temperature for fusion, but which runs very liquid, the fragments may be distributed uniformly over the bed, and melted down without being moved, if the furnace is sufficiently hot; but otherwise, a pile of metal is formed close to the fire-bridge, and as the temperature increases, the unmelted portions are drawn back into the centre, and pressed down below the surface of the slag.

When white or refined metal is used, it is said to be an advantage to bring the furnace to a high heat by firing up strongly for about a quarter or half an hour before introducing the charge; the fusion takes place more rapidly, and with less oxidation of iron, than is the case in the ordinary way.

In order to bring about the reaction of the slag upon the melted metal, it is necessary to incorporate the whole contents of the furnace well together after melting. For this purpose the temperature is lowered by checking the draught, or even throwing water upon the metal, the charge being stirred at the same time. The slag is also reduced to a more basic condition by the addition of scale or mill cinder, to compensate for the silica produced from the oxidation of silicon in the pig, which, as we have already seen, always separates when the fusion takes place in an oxidising atmosphere. When the mixture is complete, and the mass is somewhat stiffened, the reaction of the oxide and silicate of iron upon the combined carbon is apparent by the escape of blue flames of carbonic oxide; and as the temperature is increased by opening the damper, the whole of the surface of the metal commences to boil from the rapid escape of gas, and rises above the level of the working door, at the same time a portion of the molten slag flows out. The action is facilitated by constant stirring with the rabble or hooked bar. The puddler searches or sweeps every portion of the bed by moving the point of the tool in curved lines from the centre outwards towards the bridges on either side, commencing at the front. The sides are reached by a kind of scooping action, the rabbles being worked against the door-frame as a fulcrum. The tool must be changed every five or ten minutes, or it would soften and adhere to the iron if left too long in the furnace. When taken out it is cooled by plunging into a cistern or *water bosh*, which detaches the adherent cinder; the point is afterwards dressed up into shape by forging with a light hammer. Usually four tools are required to be used in the boiling of one charge.

As the carbon diminishes the ebullition becomes less violent, and the bath, from its reduced fusibility in spite of the high temperature, begins to stiffen, and malleable iron separates, or, as it is called, *comes to nature* in the form of bright points, which increase to spongy masses projecting from the bath of melted slag. Owing to the high temperature and the fine state of division in which it is exposed to the oxidising atmosphere of the furnace, the reduced metal is raised to a brilliant white heat by partial combustion. At this point of the process it is necessary to regulate the fining by preventing the too rapid agglomeration of the reduced iron; the whole contents of the furnace require, therefore, to be stirred and broken up again, so that every part may be brought under the influence of the high temperature prevailing in the neighbourhood of the flue-bridge, at the same time any pasty lumps of iron that may have adhered to the sides are detached. The reduced mass is subject to a final heat, in order to facilitate the separation of the cinder by rendering it perfectly fluid.

The last operation consists in forming up the balls, which is done by detaching from the reduced iron masses of usually from 60 to 80 lbs. weight each, and pressing them together with the tool until they are sufficiently coherent to be moved without falling to pieces. This may be done either by pressing against the bottom and sides of the furnace, or by a rolling motion, the iron being gathered up around a small nucleus like a snow-ball.

As soon as a ball is made it is placed close against the fire-bridge, and in order to keep it out of the draught of air between the working door and the flue, the second is proceeded with until the whole of the charge has been balled up; the working door is then closed, and the final heat is given.

The removal of the balls, which are of a roughly spherical form, after they are drawn to the working door with the tool, is effected by means of a long pair of tongs with curved jaws. They are first lifted to the table in front of the working door, and afterwards either dragged along the floor or carried on a wrought-iron truck to the hammer, or such other shingling machine as may be employed. After the removal, and during the shingling of the first ball, the damper and working door are shut, in order to protect those remaining in the furnace from unnecessary waste by oxidation while waiting their turn for hammering.

The old system of puddling pig iron on a dry bed is only applicable to white or refined metal: the chief difference between it and the method of boiling consists in the comparatively small quantity of slag formed. As soon as the metal has got into the pasty state it is broken up and constantly stirred, in order to incorporate the oxide of iron, formed during the melting down, with the metal. The contents of the furnace are not allowed to become perfectly fluid, and the work goes on continuously from the commencement of the stirring to the balling up. Although there is less loss of iron, and a smaller consumption of fuel, owing to the rapidity with which the operation is performed, than is the case in the boiling process, the iron produced is likely to be of an inferior quality, unless a very good description of pig is used. The actual use of sand bottoms is almost obsolete, as they give rise to a great waste of iron, the process being usually conducted on an iron bottom with a thin coating of cinder.

According to Truran, 1 ton of puddle bars is produced by 21 cwt. 1 qr. 20 lbs. of fine metal by the dry puddling, and 21 cwt. 3 qrs. by the boiling process. The former lasts from 1 to 1¼ hours, and the latter from 1½ to 2 hours.

The excellence of the iron produced depends mainly upon the prevalence of a high temperature during the period of boiling, when the heat is continued during the balling by keeping the damper open, in order to maintain an oxidising atmosphere in the furnace; decarburisation is promoted, and soft or fibrous iron is obtained. On the other hand, when the draught is checked after boiling by partially closing the damper, the hearth is filled with neutral or reducing flame from the imperfect combustion of the gases produced by the fuel, and a further elimination of carbon is prevented. The result in this case is a hard or steely iron, which breaks with a finely crystalline fracture, and may be considered as intermediate in character between soft iron and steel. By diminishing the time of boiling, and working at a low temperature, another form of granular crystalline iron may be obtained, which is hard, but deficient in tenacity, and only fit for the body or central part of common rails, where it is exposed chiefly to a compressive strain.

Although the nature of the iron obtained is greatly dependent upon the manipulation, as much or more is due to the quality of pig iron operated upon. The greater the amount of impurities, especially sulphur and phosphorus, the longer will the puddling last, and consequently, the greater will be the waste of metal. With metal of low quality it is scarcely possible to produce good steely iron, as the decarburisation must be pushed to the utmost in order to remove other foreign substances.

The quantity of slag produced in puddling varies with the metal treated. With grey pig it is greatest, as the combined silicon takes up about six times its weight of iron in order to form a fusible silicate; while refined metal, having been previously deprived in great part of its silicon in the refinery fire, makes much less. The more nearly the slag approaches in composition to a neutral (tribasic) silicate, the greater will be its fluidity, and the less its decarburising influence upon the molten pig iron, as compared with the more basic slags, containing peroxide or magnetic oxide of iron in excess, which are produced towards the end of the process. The presence of other bases in the slag, especially protoxide of manganese, have a similar effect in preventing the removal of carbon, as they increase the fluidity, so that the bath of molten slag screens the surface of the metal from the direct action of the air, without introducing the compensating oxidising agency of kindred oxides upon the combined carbon, oxide of manganese being undecomposable by carbon in an oxidising atmosphere. It is on account of this property that the presence of manganese is of great value in pig iron which is intended to be converted into steel by puddling.

As the fluidity of puddling-furnace slags diminishes with the increase of bases, it is advisable not to work with refined metal alone, as in that case the hearth bottom becomes covered after a time with an almost infusible layer of highly basic slag, like the *bull-dog* used in fettling. This inconvenience is to be avoided by adding a certain proportion of grey or white pig iron containing silicon to the charge of fine metal. Under ordinary circumstances, in puddling grey pig, the cinder is tapped off at every second heat; but with fine metal the quantity formed is so small that it may remain.

The chemical changes involved in the process of puddling have been investigated by Calvert and Johnson, Lan, Schilling, and Drassado, both in England, France, and Germany. The method followed by these chemists was similar in all cases. Samples of the iron and slag taken from the furnace at different times during the puddling of one charge were analysed, and the results tabulated. The order in which the foreign bodies are removed can then be seen by comparison of the analyses, assuming, of course, that the samples represent the average composition of the contents of the furnace at each period. In the boiling process, the oxidation of carbon is effected chiefly in an indirect manner by an excess of protoxide, or rather magnetic oxide, of iron contained in the slag, which oscillates in composition from a more acid to a more basic character at different stages of the process. Thus the amount of silica in the slag may be increased absolutely, at the commencement of the process, by the oxidation of silicon during the melting of the pig iron; and relatively, during the boiling part of the process, owing to the partial reduction by the carbon of the pig iron of the oxides of iron held in combination. On the other hand, the slag becomes more basic towards the end, when the carbon has been removed, and the reduced iron commences to burn, owing to the intense heat necessary during the operation of balling. The removal of the foreign matters in combination with the iron takes place in the following order: first, silicon; then manganese, then phosphorus; and, lastly, sulphur; the latter element being most difficultly removable. In the treatment of grey pig iron, the graphitic carbon is transformed into the combined condition after the removal of the silicon during the melting of the charge; a change that has already been noticed as occurring at the same stage in all refinery processes.

The cause of the removal of phosphorus from iron in the puddling process is not well explained. Percy supposes that it may be effected by liquation as a fusible phosphide of iron, which sweats out of the pasty mass of the ball and passes into the slags, where the phosphorus is oxidised to phosphoric acid. When a sufficiently high temperature can be commanded to melt malleable iron, as is the case in Bessemer's process, the whole of the phosphorus present in the pig iron is retained in the product. This appears to be true for any kind of iron.

The addition of oxidising fluxes other than the compounds of iron already noticed has been advocated as a method of improving iron in the puddling furnace. The chief of these is the mixture of salt, peroxide of manganese, and clay, known as Schafhaütl's powder, which is recommended as an addition in the boiling process, at the rate of about 14 lbs. to an ordinary charge of 3½ or 4 cwt. of pig iron. The oxygen given off by the peroxide of manganese and the chlorine of the salt are said to act directly upon arsenic, sulphur, and phosphorus, with the production of oxides or volatile chlorides; while the bases, alumina, protoxide of manganese, and soda, pass into the slag, giving it increased fluidity. The latter is probably the true reason of the efficacy of this flux. Sulphate of iron has also been recommended for the same purpose.

In Staffordshire two hands (puddler and underhand), in a turn of twelve hours, work off from five to seven heats, the charge being from 4 to 4½ cwt. The smaller number refers to grey pig, and the larger to mixtures containing from one-third to one-fourth by weight of fine metal. The loss of weight between the pig iron charged and the puddled blooms or bars produced is from 1½ to 2 cwt. per 22 cwt. of pig metal, or from 7 to 10 per cent. The coal burnt amounts to between 20 and 22 cwt. per ton of puddled bars. The fettling materials required in the turn of twelve hours for keeping the bed in proper order are from 6 to 7 cwt. of bull-dog, and 2 to 3 cwt. of puddler's mine, in addition to the mill scale added to the charge.

In Scotland, where dark grey metal rich in silicon is used without being previously refined, only from four to five heats of 4 cwt. are made in the same time. The loss of weight is from 15 to 18 per cent. from pig iron to puddled bars, and the consumption of coal per ton of the latter from 25 to 26 cwt. When mixtures of fine metal and grey forge pig, partly Scotch and partly hematite, are used, the results are generally similar to those obtained in Staffordshire. In Cleveland, the consumption of small coal (nuts) is from 24 to 27 cwt. per ton of puddled bars. The whole of the above quantities are in long cwts. of 120 lbs. each.

In the West Riding of Yorkshire, in the neighbourhood of Leeds and Bradford, a very high quality of wrought iron is made from cold blast refined metal by puddling in small heats, the stirring being continued longer than is usually the case, in order to obtain uniformity in the product. The furnace is of comparatively small size, with a very high stack, in order to command a strong heat. The charge, weighing 3 cwt., is heated to redness before its introduction to the puddling furnace, so that the melting down requires only from twenty to twenty-five minutes, and the whole operation about one hour and twenty minutes: nine heats are made in twelve hours. The balling is performed as much as possible in a reducing atmosphere, by closing the damper, as the iron is of a bright crystalline steely character, and is not decarburised to the same extent as ordinary fibrous iron. Only three or four balls, weighing from 80 to 90 lbs. each, are obtained in one heat, which, after shingling under a helve hammer into plates or stamps from 10 to 12 inches square, and about 2½ inches thick, are broken into pieces by blows from a heavy weight falling from a considerable height. These pieces or stampings are assorted according to the fracture; those that are most uniformly crystalline are reserved for the manufacture of hard bars, such as railway tires, while those showing fibre are better fitted for making boiler plates and wire rods. The consumption of coal is very large, being 30 cwt. per ton of fine metal treated, or 37½ cwt. per ton of blooms produced. When the double furnace is used the charge is twice the ordinary weight, or from 6 to 8 cwt., the time required for working off the heat being the same.

In Belgium the average weight of the charge is 230 kilogrs. (4·6 cwt., short weight). According to the quality of metal employed, the time required for each heat is from 1½ to 2¾ hours,—namely, 2¼ to 2¾ hours with grey pig, 1¾ to 2¼ hours with white pig, and 1½ to 2¼ hours with fine metal. The loss of weight is from 7 to 10 per cent. The coal burned is equal in weight to that of the puddled bars produced.

The general arrangements of a gas-puddling furnace, used in Carinthia are represented in the longitudinal section, Fig. 26. The fuel is air-dried wood, which is converted into combustible gas in the generator *a*, a rectangular chamber, lined with fire-brick, of a capacity of about 14 cubic feet, by a stream of air introduced at a pressure of half an inch of mercury, through the lower branch of the blast main at *b*. The combustion of the gases is effected by a second blast, introduced immediately above the fire-bridge, through the inclined twyer

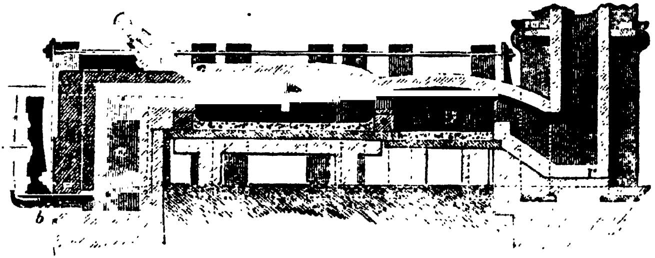


Fig. 26.—Carinthian gas-puddling furnace.

c, which is of an oblong form, extending completely across the bridge, with an aperture of 7 inches in depth. By previously circulating through the hollow space in the cast-iron side plates of the bed, the air is heated to a temperature of 200°, producing a much more active combustion than is the case when the gases are burnt with cold air. A second bed is used for heating up the metal for the following charge by the waste flame during the period of balling, an arrangement that, as has already been stated, is found to save both time and fuel. The remaining details do not call for any particular remarks, being of the ordinary kind adopted elsewhere.

In Styria, where lignite is used for puddling, the consumption is from 22 to 24 cwt. per ton of blooms, a result that is highly favourable, not exceeding the average of furnaces where coal is burnt, allowance being made for the difference in calorific value of the two classes of fuel. This is in great part due to the high quality and small amount of carbon and silicon in the pig iron operated upon. The heat of 4 cwt. is worked off in an hour, having been brought to an orange-red heat before melting by exposure in a second hearth, during the balling of the preceding charge. The loss of weight on the metal is from 6 to 10 per cent.

When peat is used, from 240 to 360 cubic feet are required in the production of a ton of blooms, or from 200 to 280 cubic feet of wood. From the published accounts of the working of furnaces using these fuels, there does not appear to be much difference whether they are burnt on a grate, or previously converted into gas, in the manner described above. The most economical work appears to be at Neuberg, in Styria, where only 100 cubic feet of air-dried wood are consumed in the production of a ton of blooms. The metal, of a white or strongly mottled character, smelted with charcoal from spathic ore, is puddled in a double furnace, in charges of 8 cwt.; the heat lasts two hours, the loss of weight being from 5 to 6 per cent. At Lippitzbach, in Tyrol, one ton of blooms is produced from 1·047 tons of pig iron, with a consumption of 1·011 tons of wood scorched or torrefied.

In Staffordshire, a certain quantity of scrap iron is sometimes added in the puddling furnace, in order to improve the quality of the product as soon as the iron comes to nature. When the fragments are at a white heat, they are incorporated with the contents of the furnace, which are then balled up in the ordinary way. It is obvious that if the scrap added be of good quality, it will have a beneficial effect, by spreading the absolute amount of impurities contained in the puddled iron over a greater weight of finished iron, and thus producing a relatively purer article.

The work of the puddling furnace is divided between the puddler and his underhand: the latter attends to the firing, and also does part of the stirring or rabbling; the last and heaviest portion of the work, together with the forming the balls, being usually done by the former. The tools employed are principally of two kinds, namely, long straight chisel-edged bars or paddles, and hooked bars with similar flat ends or rabbles, weighing about 60 lbs. each. The number of tools used in the working of one charge depends upon the quality of the iron, and may vary from three or four to eight, according to the amount of work required. When withdrawn from the furnace, the points are coated with molten cinder, which is removed by quenching the bar into a cistern of cold water or *water bosh*, placed by the side of the stack. The cinder deposited at the bottom of the bosh is afterwards added to the charge in the boiling process.

In order to lessen the great amount of labour involved in working the charge, various mechanical appliances have been proposed in substitution for manual puddling, but these have not as yet been adopted to any great extent. The different plans proposed for this purpose may be classified under two heads, namely, those imitating the motions of hand-stirring, by moving the tool through a curved path by a combination of reciprocating rotatory mechanism, and those using rotating or oscillating hearths. Of the latter kind are the furnaces proposed by Tooth, Menelaus, Bessemer, and others. The molten iron is fined by exposing it to oxidising influences in a cylinder lined with clay, or other refractory material, occupying the position of the hearth in an ordinary puddling furnace, which receives a slow movement of rotation about its long axis. The charge, in addition to being turned over, is traversed from end to end of the cylinder by inclining the lining from the fireplace to the flue, and in the reverse directions at opposite points of the circumference. The ball is withdrawn from the furnace by removing the puddling chamber, and tilting it up on end. These furnaces have not hitherto been successful, owing to the difficulty of getting linings to stand the scouring action of the metal. Menelaus found the best material for this purpose to be titaniferous iron ore, which was used in solid blocks. The ordinary fettling materials, such as bull-dog, were quite useless. The above represents our knowledge of rotating furnaces when this work was written; how it has progressed since will be seen by the account of Danks's and other furnaces at p. 321.

One of the simplest of the first class of contrivances or mechanical stirrers, by Eastwood, is represented in Fig. 27. The rabbling tool, *a*, is suspended in a stirrup at the end of the longer arm of a bent lever, which receives an alternating motion by a rod, *b*, connected with a crank on the main driving shaft. The centre of oscillation of the bent lever is placed at the end of an inclined jib, which can be moved laterally through a small arc by another rod, *c*, working on a pin attached to a screw-wheel, *d*, driven by a worm on the main shaft. The action is as follows:—Motion is given by a chain passing over a pulley in the main shaft at *e*. The rabble is moved backwards and forwards across the hearth once in each revolution, at the same time that its centre is shifted by the movement of the jib.

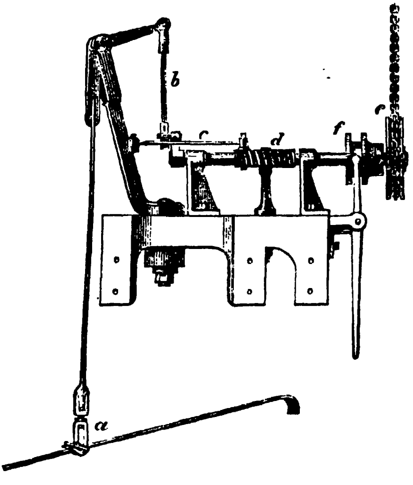


Fig. 27.—Eastwood's mechanical puddler.

through a small distance by the screw gearing, thus producing a compound motion in the tool, and causing it to travel over every portion of the furnace bottom. The machine is bolted to the back of the casing plate on the working side of the furnace; the driving pulley is connected with the shaft by a fast-and-loose clutch, *f*, so that it may be readily put in and out of gear as required.

Ellerhausen's process for simplifying the work of the puddler, by the use of an intimate mixture of pig iron and oxydising substances, such as hematite or magnetite, resembles the first operation of the Bergamask forge process, with this difference, that the mixture of molten iron and finely-divided flux is made mechanically, instead of by manual labour on the hearth. The cast iron is run directly from the blast furnace, through a gutter, which delivers it, in a broad thin stream, into an ingot mould; a similar stream of finely-divided hematite or magnetic ore being supplied simultaneously through another channel. In this way a porous mass, known as a pig bloom, is obtained, weighing not quite 1 cwt. The moulds form a ring on the circumference of a cast-iron table, divided into 54 partitions, and about 2 feet long and 8 inches deep, which rests upon friction rollers, and is slowly revolved by steam power, so as to bring each division in succession under the channel supplying the metal and ore. The table makes four revolutions per minute, and the total weight of the 54 blooms is 50 cwt. At Dowlais, where the process was tried experimentally, considerable difficulty was sometimes experienced in breaking up the blooms in the puddling furnace, and a Blake's rock-breaker was tried, for the purpose of reducing the size of the blooms before charging them. The best results were obtained with the use of 15 per cent. of red hematite and 5 per cent. of coke, when an increased yield of about 4 per cent. over that of the ordinary process was obtained. When the amount of ore added was larger the furnace worked cold, and the slag was not sufficiently fluid, and the work was harder than ordinary puddling. This process, though found advantageous in America, on account of the saving in labour, has not been adopted in this country.

According to Parry, the amount of phosphorus contained in puddled iron is from 20 to 25 per cent. of that originally present in the pig iron, and of sulphur about 20 per cent. If, therefore, the iron so obtained is reconverted into pig iron by fusion with carbon, taking care that neither sulphur nor phosphorus is re-introduced, the proportion of these substances in the iron obtained from the purified metal by a second puddling will be almost inappreciable. Thus, if in the first instance the mine pig contained 0·75 per cent. of phosphorus, this would be reduced on the first puddling to 0·15 per cent., and on the second to 0·03 per cent. Parry's process of double puddling is founded upon the above property. The material treated is the waste produced in finishing bar iron, known as crop ends; these are melted with coke in a cupola furnace, differing from that ordinarily used by iron-founders in having a strongly-inclined twyer, in addition to the ordinary horizontal one, through which the blast is introduced. It is, in fact, a combination of a blast furnace with a refinery, and the product is very similar to that obtained in refining with coke, namely, a metal of low degree of carburisation, almost entirely free from silicon. This is run into moulds, and afterwards puddled in the usual way, giving a pure quality of iron, which it is suggested may be still further improved by repeating the fusion in the cupola, and puddling a third time. The consumption of coke is at the rate of about 30 or 40 per cent. of the weight of the scrap iron converted. It is, of course, necessary to prevent the iron taking up sulphur from the ash of the coke by a proper addition of limestone or other appropriate fluxes in the cupola. For this purpose, it is suggested that the coke may be impregnated with salt or carbonate of soda by steeping it in a solution of these salts for some time before it is required for use

The rotatory puddling furnace, which was originally proposed by Mr. Menelaus, and used experimentally for a short time at Dowlais, when it was abandoned owing to the difficulty of obtaining a sufficiently suitable and refractory material for the lining, has within the last two years been much improved and perfected by Mr. Danks in the United States, who has made the

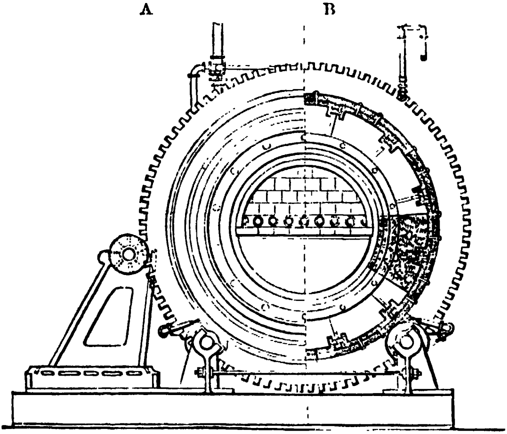


Fig. 27a.—Danks's rotatory puddling furnace.
A. *Half-elevation of rotatory chamber.*
B. *Half-section through rotatory chamber.*

process a technical success. The furnace represented in Fig. 27*a* takes a charge of 600 lbs. at one heat. Fig. 27 *b* is a longitudinal section. In Fig. 27 *a* the right hand half B represents a transverse section through the centre of the furnace, and the left hand A the elevation at the forward end. Fig. 27 *c* is the elevation of the flue end. The furnace consists of three parts, a fixed fireplace and bridge, a moveable puddling chamber taking the place of the ordinary bed, and a flue which is composed of a fixed part leading to the chimney and a moveable part connecting it with the chamber.

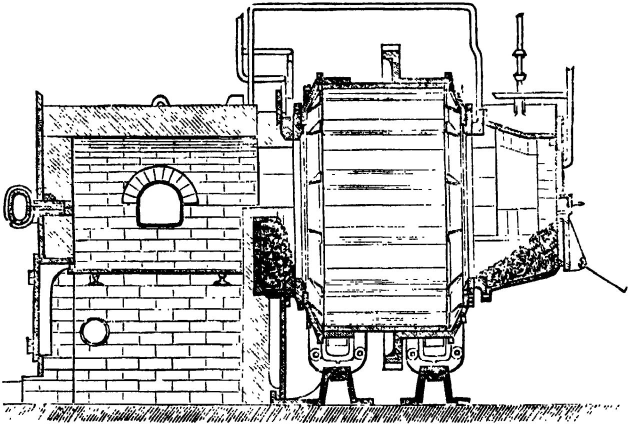


Fig. 27*b*.—Danks's rotatory puddling furnace. Longitudinal section through fireplace, puddling chamber, and moveable flue.

The fireplace is of the ordinary description, with an air-blast for increasing the intensity of the combustion. The air is supplied partly through a pipe below the grate, and partly through two series of small twyers in the back wall at the level of the firebridge, the amount being regulated by a valve in the admission-pipe. The firebridge, which is of cast iron cooled by a current of water circulating through it, is faced on one side with firebrick, and on the other by a layer of fettling similar to that used in the puddling chamber. The outside of the fireplace is formed by a thick cast-iron ring, also cooled with water, whose outer surface is cast in chill, and forms a rubbing face for a similar ring on the rotating part.

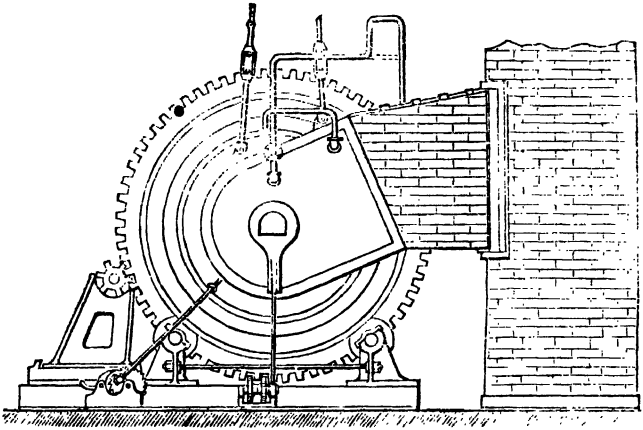


Fig. 27c.—Danks's rotatory puddling furnace. Transverse elevation at flue end.

The puddling chamber is a cast-iron cylinder with conical ends 4 ft. long by 5 ft. 3 in. greatest diameter. It is bound with iron hoops and faced with flat rings, which rub upon similar surfaces fixed in the faces of the fireplace and flue. The cylindrical body of the chamber is formed of cast-iron segments kept together by the conical ends, and has twelve radial ribs projecting internally for keeping the lining or fettling in its place. At either end of the cylinder is a belt turned smooth, forming the bearing surfaces for the chamber upon the friction rollers which support it, and in the centre is a toothed ring which receives motion from a pinion driven by a pair of small steam-engines. The front conical cover has a tap-hole for letting out the cinder. The moveable flue is made of cast iron, lined like the puddling chamber, and cooled by water. In the end is a stopper hole through which the process can be watched, and the rabbling-bar, or tool for tapping the slags or balling the iron, can be introduced. When at work, the moveable flue is kept in position by two stays connected with ratchet wheels, but it is also suspended by two rods to a truck with rollers, which moves on an overhead railway, so that by disconnecting the lower stays it is left suspended to the truck, and may be moved to one side, leaving the end of the chamber open for withdrawing the ball. In this way the necessity of making a working door in the chamber is avoided. The moveable piece is connected by a short brick flue with the chimney-stack in the usual way. The fettling or lining of the chamber is made in two thicknesses: the first or initial layer consists of a mixture of crushed iron ore and slacked lime brought to the consistency of mortar, which is filled up to about an inch above the projecting ribs. One-third of the surface is covered at a time, the coating being dried by a wood fire before adding a new portion. The whole operation requires from 10 to 11 hours. The ore should not contain more than 5 per cent. of silica, and be free from combined water, which is likely to crack the lining when driven off by subsequent heating. About 30 cwt. of ore and 4 cwt. of lime are used to form the initial lining. The fettling proper is formed by melting upon the initial lining pulverized iron ore, hammer-slag, and scale, in quantity sufficient to form a pool in the bottom of the cylinder, into which pieces of harder ore are thrown in until the surface is studded with lumps projecting from 2 to 6 in., when it is allowed to set, and the operation is repeated with the cylinder in a different position until the interior is completely lined. From 2 to 2½ tons of ore are required for a 700-lbs. furnace, and about 3 tons of coal are required for the different operations of drying and melting the fettling.

The steps in the operation of puddling are similar to those of the ordinary process, the rotary motion of the chamber being substituted for the action of the puddler's rabble. The pig iron is charged through the flue end upon a quantity of cinder, from 30 to 60 per cent. of its own weight, either in a solid or melted condition. In the former case the time required for melting down is from 30 to 35 minutes, during which period the chamber is partly rotated in order to bring the charge equally under the action of the flame. When the whole charge is thoroughly melted, the chamber is made to revolve from two to three times in a minute, for five or ten minutes; a stream of water is then injected to solidify a portion of the supernatant cinder, which, as the chamber turns, is carried into the bulk of molten iron, and in this way a continuous action, resembling that produced by the incorporation of scale and other oxidized iron products in the ordinary furnaces by the puddler's rabble, is kept up until the iron begins to thicken, when the motion is stopped, and the fire is raised until the cinder being perfectly liquefied, it is run off through the tap-hole, the chamber being brought into a proper position for the purpose. The rotation is then continued at six to eight revolutions per minute until the iron begins to adhere together, when the speed is reduced to two revolutions, and the ball commences to form. If any loose pieces are found, the puddler moves them to one side, and by turning the furnace partially, so as to tumble the main mass over them, they are made to coalesce with it. The fore end of the ball is solidified by a few blows from a tool introduced through the stopper-hole. The flue piece is then moved to one side, leaving the end of the chamber open, and the ball is removed by a fork worked by a crane, and carried to the squeezer, where it is shingled, and afterwards rolled to a puddled bar in the usual way. The time of working one charge lasts from an hour to an hour and a half, according as the pig metal may be white or grey. From eight to ten charges may be made before the fettling requires to be repaired. The average consumption of fettling materials, ore scrap, and forge cinder, is about 12 cwt. per ton of puddled bars produced. The coal used is 22 cwt., some of which may be saved by melting the metal in a cupola instead of melting it in the furnace. A special form of squeezer is used, consisting of two corrugated rolls placed horizontally in the same plane, moving in the same direction, making 15 or 20 revolutions per minute. Above these is placed a large excentric, or cam, geared to the rolls, and moving in the same direction with the same circumferential speed; at the side of the frame is a horizontal steam-hammer, which hammers the end of the bloom as it is being rotated. When the bloom is sufficiently squeezed, which is done in two revolutions of the cam, it is turned out in the form of a cylinder with squeezed ends, and can be removed to the reheating furnace at once. Owing to the large surface of the lining and the exclusion of air, the removal of the carbon silicon, and other foreign matters in the pig iron is effected entirely by the peroxide of iron in the fettling with the reduction of a corresponding portion of iron which goes to increase the weight of the ball, so that the amount of puddled bar produced is, under favourable conditions, somewhat greater than that of the pig metal charged. Mr. Snelus, in his report to the Iron and Steel Association, points out that the yield from white pig iron in the Danks's furnace is found to be inferior to that from grey, there being a difference of from 1 to 1½ cwts. in the quantity required to make a ton of puddled bars, in favour of grey over white forge pig. When the puddling had to be done by hand, the use of white pig saved a great deal of labour; but, with the adoption of machinery, the above advantage, in addition to the higher quality of the product, will probably render it more economical to make forge pig moderately grey and silicious rather than white, in spite of the increased consumption of fuel in the blast furnace required for its production The working power of the Danks' furnace is about four times that of the ordinary single puddling furnace, or rather twelve of the former may be taken as equivalent to fifty of the latter.

A somewhat similar furnace has been introduced by Mr. Spencer at Hartlepool. Instead of being a cylinder, the revolving chamber is a long box of square section, measuring 9½ ft. in length by 4⅔ ft. in the side. The fettling material is the cinder known as *best tap*; it is obtained from reheating furnaces which have iron bottoms covered with purple ore, instead of the sand bottom formerly used. This cinder is very free from silica and phosphorus, and can be easily melted. It is cast into troughs or divisions formed by projecting ribs on the sides of the chamber, and built in blocks properly moulded, the whole being cemented together by melted tap into a smooth and regular form. The repairs are done by running in the same material melted from a ladle through a spout to the place where it may be required. In an early form of the furnace the chamber was placed with its sides skew to the axis of rotation of the chamber, but latterly the rectangular form has been adopted in preference. In other respects the working of this furnace is similar to that of Danks's, but as the cast iron is introduced in a melted state, the heat is worked off in less time.

Another form of rotating furnace has been recently introduced by Mr. Siemens. It resembles Danks's, but in the form of the revolving chamber differs from it in many important particulars, especially in the fettling, the aluminous brown iron ore known as Bauxite being employed for that purpose. This contains when calcined from 44 to 68 per cent. of alumina, 28 to 52 per cent. of peroxide of iron, and 3 or 4 per cent. of silica; it is rendered coherent by a small addition of clay or silicate of soda, and about 6 per cent. of graphite is added to the mass, which renders it practically infusible by reducing the peroxide of iron to the metallic state. This material has the advantage of becoming converted under the action of strong and continued heat to a solid mass of emery of intense hardness, besides being infusible, and therefore capable of resisting the mechanical scouring of the charge as well as great heat and chemical action. The fireplace is of the ordinary regenerative form for burning intensely heated gases. The flame enters the chamber, by a flue divided by a midway partition-wall, with sufficient velocity to traverse its whole length and return through the other division on its way to the regenerators. The moveable flue of Danks's furnace is replaced by an ordinary sliding door lifted by a chain and counterpoise. The chamber, which is about 7½ ft. in diameter, and 9 ft. long, is provided with two trains of wheel-gearing, by which it can be turned either very slowly, from 4 to 5 revolutions per hour, or more rapidly, from 60 to 80 revolutions in the same time. The Bauxite lining is about 7 in. thick. There is a tap-hole on the working end for discharging the slag into a pit below, where it is received in tubs mounted on wheels for facility of removal. The object of this furnace is not for puddling, but for the production of malleable iron or steel directly from the ore. It is worked as follows. The ore is broken up into fragments of the size of peas or beans ; to it is added lime or other fluxes, so as to form a basic fluid slag with only a little protoxide of iron. With hematite or silicious ore aluminous ore may be used, and also manganesiferous ores with advantage About 20 cwt. of materials are charged, and the furnace is slowly revolved for 40 minutes, when the contents will be raised to a bright red heat. From 5 to 6 cwt. of small coal is now added, and the rotative velocity is increased. A rapid reaction takes place: the peroxide of iron being reduced to the magnetic state, begins to fuse, and at the same time the carbon precipitates metallic iron, while the fluxes take up the silica of the ore forming a fluid slag. The slow action is again employed, the mass being turned over and over, continually presenting new surfaces to the heated lining and flame within the rotator. During this period, carbonic oxide gas is evolved by the action of the ore on the carbon, and heated air alone is introduced to effect its combustion, the gas from the gas-producers being almost shut off. When the reduction of the ore is nearly complete, the tap-hole is brought into proper position; the rotatory motion is stopped, and the cinder is tapped off; afterwards the quick speed is put on, whereby the loose masses of iron are rapidly collected into two or three balls. These are taken out and shingled in the ordinary way; the furnace is tapped again, and is ready for another charge. The time of working one charge rarely exceeds two hours; and at 10 cwt. per charge the furnace is capable of yielding 5 tons of puddled bars in twenty-four hours. If anthracite or hard coke be used for reduction, it should be crushed much finer than coal or lignite, while wood is to be used in larger pieces, the object being to consume the whole of the reducing material less its ash, which is taken up by the fluxes to form part of the slag. If it is intended to form cast steel instead of iron, the balls may be transferred without shingling to the bath of the Siemens' steel melting furnace. This process, which is still in the experimental state, promises to be of great value in countries where, for want of good fuel, blast furnaces cannot be erected. The fuel used being divided, part being burnt in the gas-producers, only that required for the reduction of the oxides of iron being brought in contact with the charge, there is so much less ash to be fluxed, and proportionately less chance of the iron being contaminated with impurities than when the whole amount is consumed in contact with the charge, as in the blast furnace. The great source o economy of fuel is however to be looked for in the fact that whereas blast-furnace gases contain large quantities of carbonic oxide, and are given off at 350°, the gas of the rotator is essentially carbonic acid, which passes from the regenerator to the chimney at about 175°. The process, although originally designed for use with pure rich ores, gives iron of good quality with low-class ores.

In the latter case the loss of iron is considerable; part of it being used as flux in order to prevent the reduction of phosphorus, as in the Catalan process.

CHAPTER XVI.

FORGE AND MILL MACHINERY.

THE machines used in the compression and welding of the rough balls of malleable iron into blooms are of two different kinds, namely, hammers and squeezers, the former acting by percussion, and the latter by compression. In addition to these, it is usual in puddling forges to reduce the blooms obtained by hammering or squeezing to rough bars by passing them at the same heat through a rolling mill.

By the term forge is usually understood those portions of iron works which are intended for the production of puddled blooms or rough bars, including the puddling furnaces, shingling machines, and puddling rolls. The remaining portion of the works, where the rough bars are reheated and reduced to finished or merchant iron, is known as the mill, and includes the reheating or balling furnaces, and the various kinds of rolling mills and finishing machinery employed in the production of plates, bars, and other merchantable products.

The oldest and simplest class of machines used in forging blooms are lever hammers. These are of two classes, namely, tilt hammers, where the axis is between the point of application of the cam and the head, and helves, or lift hammers. In the former, the head is placed near the end of the longer arm, while the cam acts at the end or tail of the shorter one. In lifting hammers, or helves, the hammer block and the lifting cam are placed on the same side of the fulcrum. These, again, are of two kinds—the tenant, nose, or frontal helve, where the cam acts upon a tongue immediately in front of the hammer-block, corresponding to a lever of the second order, and the belly helve, which has the cam shaft placed below the floor, and acting about midway between the fulcrum and the head, forms a lever of the third order, so that the anvil is free on three sides. In all of the preceding varieties the axis of rotation of the cam ring is placed at right angles to the line of the hammer. Besides these, there is another old-fashioned form known in Germany as the pitch-up hammer, which differs from the belly helve in having the line of rotation of the axis parallel to that of the hammer stem.

Tilt hammers are usually made of small sizes, the head of the heaviest weighing about 5 cwt.; they are driven at considerable speed, and are used rather in drawing out bars, making spikes, and finishing work generally, than for shingling blooms in the first state. The shaft or stem is made of one or more beams of straight-grained springy wood, according to size, hooped together with rings of wrought iron. The pivots are either attached to a broad central hoop, or are mortised through the shaft. The head is usually shaped like that of a large sledge hammer.

Helve hammers, such as were formerly in general use in puddling forges, have been made of all weights up to 10 tons. The usual sizes are between 30 cwt. and 5 tons; they make between 70 and 100 strokes per minute, with lift of between 16 and 20 inches. In Staffordshire, shingling helves are used from 5 to 6 tons in weight, while those for blooming piles for finished iron average from 7 to 8 tons. Seen in plan, the helve is a ⊢ shaped mass of cast iron; the cross arms form the bearing, the hammer face of wrought iron being keyed into a conical socket at the opposite end for convenience of renewal. The use of the long heavy cross arm for the pivots is necessary to prevent the mass of the helve from shifting in its bearings, which are open. The height of the lift may be regulated by the amount of projection given to the tongue or wiper acted upon by the cam. In all cases it is necessary for the preservation of the machine never to allow the hammer to fall directly upon the anvil. For this purpose, when not in use, a stop or gag of iron or wood is placed between the head and the anvil, which lifts the shaft just clear of the action of the cam. By placing a piece of iron on the tongue of sufficient thickness to allow the cam to come in contact with it, the hammer is lifted, and the removal of the stop is again brought into working order.

The foundations of forge hammers require to be very massive, in order to withstand the violent shaking to which they are subjected. Large, squared balks of timber upon a bed of stone masonry or concrete are usually employed, piled crossways on end for carrying the framings of the hammer and cam-ring shaft The anvil is a block of cast iron several times the weight of the hammer, standing independently, so that its vibration may not be transmitted to the bearings of the fixed parts.

Fig. 28 is a longitudinal elevation of a frontal helve weighing 3½ tons, adapted for a forge driven by water power. The following are the weights of the principal parts:—

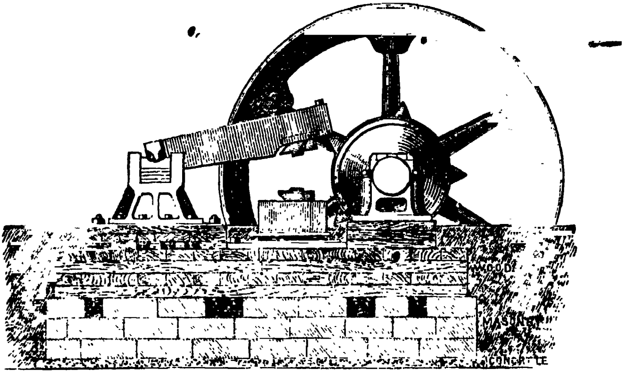


Fig. 28.—70-cwt. Shingling helve.

Weight of helve	70 cwt.
Anvil	150 „
Cam ring	125 „
Fly wheel	120 „
Main shaft	90 „

The hammer is lifted five times in each revolution of the shaft; the height of the lift is 16 inches. A water wheel of 25-horse power is required to drive it.

In water-power forges with small hammers of from 5 to 9 cwt. a wooden spring beam is often used for augmenting the force of the blow by the violent velocity of descent. This construction was in general use in Europe before the introduction of steam power, and numerous instances of it are still to be found in Sweden.

Where water power is used, especially in small forges, each hammer is generally driven by its own wheel, the axis of the latter moving the cam ring directly without intermediate gearing. In forges worked by steam power, where several machines are driven by a single engine, the hammers or helves are connected by gearing wheels to the driving main shaft, being usually placed as near to the puddling or heating furnaces as possible.

The working faces of both hammers and anvils are subject to great wear, and require to be replaced at short intervals. They may be made to last for a considerably longer time when kept cool by a current of water circulating through them. This method was introduced by Condie, the inventor of the water twyer, but does not appear to have been adopted to any great extent.

In erecting new forges at the present time, direct-acting steam hammers are generally preferred, instead of the helve, for shingling and balling purposes. This machine, as is well known, was introduced by Nasmyth in 1842, and still maintains its original construction in most essential particulars, although it has been largely modified in details, both by the inventor and other makers. It consists essentially of an inverted cylinder, vertical, high-pressure engine, supported by an arched or inverted V-shaped framing, formed of two standards of cast iron. The piston rod passes through the lower cylinder cover, and is directly connected with a heavy hammer block or tup, which moves vertically between guides attached to the inner faces of the standards. In the single-acting form, the steam is employed only for lifting the hammer block, which delivers its blow with the impact due to the fall alone; but in the double-acting or top steam hammer, the force of the blow is increased by allowing the steam to act on the upper surface and accelerate the speed of descent. A great advantage possessed by the steam hammer consists in the power of regulating the force of the blow according to the necessity of the work, as the block may be stopped at any portion of its stroke by cushioning or checking the exit of the exhaust steam. In shingling blooms, for instance, at the commencement, it may sometimes be advisable to consolidate the ball by short, light strokes, afterwards increasing the force by working with a longer fall as the iron becomes harder and more compact. This cannot be done with a helve hammer, whose height of fall, and consequent impact, is invariable. The weight of the hammer block varies with the nature of the work. In puddling forges for shingling ordinary-sized blooms, hammers of from 30 to 60 cwt. are commonly used. One of 50 cwt. is sufficient to do the work of twelve furnaces, and may be worked by the waste heat of one or two reheating furnaces. In the blooming and forging of heavy masses, such as piles for armour plates, marine engine-crank shafts, and large, irregular forgings for ships, as well as in steel works, very much larger sizes are employed, the weight of the block ranging from 5 to 50 tons. Hammers of the largest size are usually only made single-acting; the use of steam above the piston being rarely resorted to when the weight is more than 12 or 15 tons.

Fig. 29 is a side elevation of a double-acting steam hammer constructed by Thwaites and Carbutt, of Bradford; it is reduced from a drawing kindly furnished by the makers. The hammer block or tup, weighing 8 tons, is attached by a thin cylindrical rod, as in the original Nasmyth hammer, to the steam piston, which is 28 inches in diameter, and makes a stroke of 6 feet in length. The arrangements for admitting and exhausting the steam above and below the piston are similar to those of an ordinary high-pressure steam engine. The slide valve is of a tubular form, and balanced against the steam pressure in the valve chest,

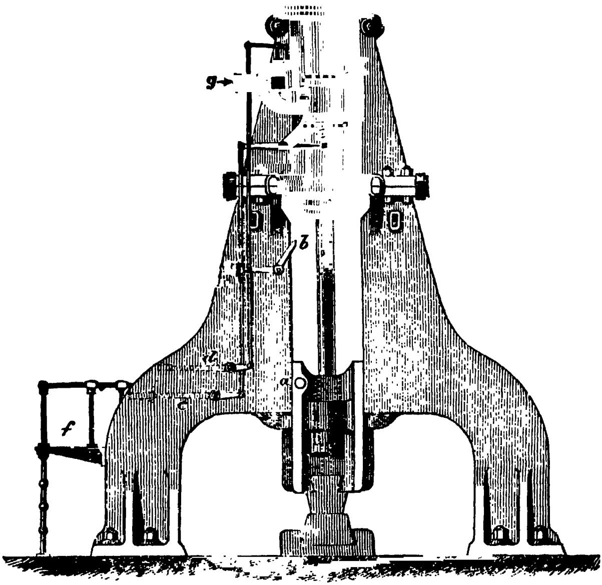


Fig. 29.—Thwaites and Carbutt's 8-ton double-acting steam hammer.

so that it may be readily moved by hand by means of the lever, *c*. *d* is the handle which moves the steam admission or regulator valve. The length of the up stroke is determined by the tappet, *a*, on the hammer block, which strikes against the arm of the bent lever, *b*, and moves the slide valve, so as to open the exhaust passage, which allows the steam from below the piston to escape into the atmosphere at *e*. The principal hammerman stands on the raised platform, *f*, having the valve levers close at hand, at the same time commanding an uninterrupted view of the work in process of forging on the anvil.

In small hammers below 12 or 15 cwt., such as are used for heavy smithing, and instead of the old tilt hammer in steel works, the framing is often reduced to a single standard overhanging its base, giving a clear working space on three sides of the anvil. Wrought-iron standards have lately been introduced.

Another type of steam hammer is that having a piston with two unequal surfaces exposed to the action of the steam, by employing a very thick piston rod. The lower or smaller surface is constantly in connection with the steam by an open port, while it is only allowed access to the larger face during the driving portion of the stroke.

Condie's hammer is distinguished by the peculiarity of having a fixed piston and a movable cylinder, the latter being cast in one with the hammer block. The piston is suspended by a rod connected with a ball-and-socket joint to the top cross bar of the framing.

In many modern hammers parallel guides below the cylinder are not used, the piston being prevented from turning by using a rod of angular or irregular section, such as a square or a cylinder, with a portion of its surface planed down to a flat face, passing through a stuffing box of a similar figure.

The anvils of steam hammers require to be of great weight, and so arranged as to stand completely clear of the ground carrying the framing. For moderate sizes, a convenient foundation may be made of squared timber, placed on end above a bed of broken cinder beaten hard, or concrete; but in the monster hammers used in steel works, the anvil and its foundation are built up of masses of cast iron. Thus in Krupp's 50-ton hammer, which has a maximum lift of 10 feet, the anvil, weighing 185 tons, is carried upon a substructure of cast iron, formed of eight blocks, weighing from 125 to 135 tons each.

Ramsbottom's horizontal hammer consists of two blocks or rams of great weight, supported by friction wheels, travelling on a short level railway, which can be drawn together or separated by a vertical steam engine acting upon a system of link rods. There is no anvil. The mass to be hammered is supported upon a carriage on a central platform, and is struck simultaneously on either side by the meeting of the rams. The general construction of the machine is shown in Fig. 30. *a a'* are the two hammer blocks, which are moved by the piston, *b*, of an ordinary double-acting steam engine by means of the connecting rods, *c c'*. *d* is the slide valve, and *e* the admission valve, both of which can be worked by hand levers. The ingot, in process of hammering, is fixed upright in a cast iron carrier, *f*, united by a link rod with a

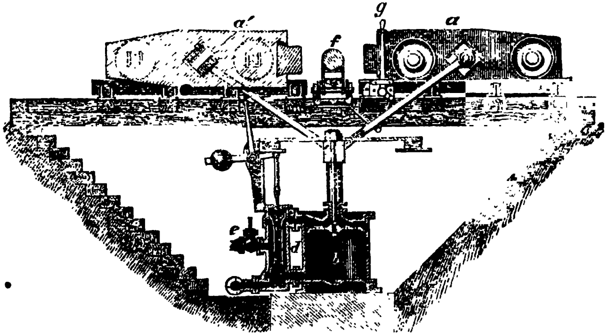


Fig. 30.—Ramsbottom's duplex steam hammer.

lever carrying a counterbalance weight at the opposite end. A hand lever, *g*, attached to the same shaft, serves to raise or lower the ingot, so as to bring a fresh portion of its length within the range of the hammers.

In the newest form of this hammer, the blocks or tups, weighing 30 tons each, are driven directly by a pair of horizontal steam engines, without the use of link rods. Each tup is driven independently by its own piston, but a provision is made for equalising the motion by a projecting arm carrying a nut, which travels on a long screw running parallel with the line of motion, whereby, in the event of one mass travelling faster than the other, the screw acts as an auxiliary driving power to the slower-going one, and brings it up to the speed of the other, so that both may strike the ingot at the same moment.

Another class of hammer sometimes used for small work combines the piston and cylinder with the method of lifting by cams. The hammer resembles an ordinary stamp head, moving vertically between guides by means of a rotating shaft armed with cams. The upper part of the rod carries a piston, which compresses air in the cylinder during the up stroke, the power so expended being given out by the expansion of the air during the down stroke, giving an increased force to the blow, similarly to that obtained when steam is used on the top of the piston in an ordinary steam hammer.

In all cases the striking faces of hammers and anvils are made removable, and are attached by dovetailed wedges, fitting into a corresponding groove on the blocks. Besides the plain faces for ordinary forging, swages and moulds are often used, as, for example, in drawing round bars, or swaging up spherical cast-steel shot.

Squeezers. In these machines the welding of the ball is effected by pressure applied without impact. They are of two kinds, namely, lever and rotary squeezers. In the former class, a lever of cast iron is made to oscillate about a fixed centre by means of a crank and connecting rod attached to the end of one arm. The opposite arm carries a jaw or plate of cast iron, which may be either flat or serrated with parallel triangular teeth, working against a corresponding fixed jaw, placed in the position occupied by the anvil in an ordinary lever hammer. The ball is introduced between the jaws of the machine at the widest part, and is pushed backwards as its thickness diminishes; the ends are compressed by placing the bloom on end between the jaws at the greatest opening. Fig. 31 is a longitudinal elevation of a double squeezer, *i.e.*, having a pair of working faces in connection with either arm of the lever, in use at Dowlais, in South Wales.

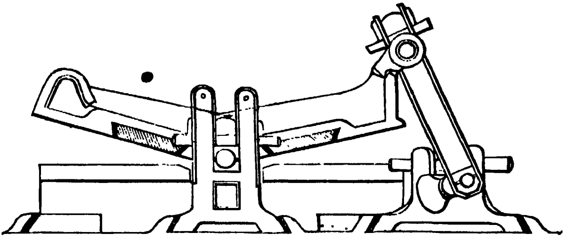


Fig. 31.—Double squeezer. Dowlais (Truran).

The rotary squeezer consists of a cylinder, whose surface is studded with blunt triangular teeth, having its axis of rotation placed either horizontally or vertically within a fixed circular casing of cast iron similarly roughened, and forming from one-half to three-quarters of an entire circle. The axis of the moving cylinder is placed eccentrically with regard to that of the case, so that although their surfaces are parallel, the distance between them diminishes in the direction of the rotation. The ball is entered at the widest part, and being carried forward by the action of the cylinder, is gradually reduced in thickness by compression against the surface of the casing, and emerges at the smaller aperture ready for the rolling mill. As there is no means of regulating the distance between the two pressing surfaces, it is necessary to work with balls of a tolerably regular figure, and as much as possible of a uniform size. In Belgium one of these machines is considered able to do the shingling for fifty puddling furnaces. The speed should not exceed twelve revolutions per minute.

Sometimes squeezers are arranged to be driven by a steam engine attached to the outer arm of the lever, but more generally they are connected to the driving shaft of a rolling mill, as, for instance, that employed in rolling blooms into puddled bars.

In the manipulation of very heavy masses, such as in welding the piles for large plates, forging of steel ingots, &c., where a powerful compressing force is required, hydraulic squeezers, or forging presses, may be used with advantage. As an example of this class of machine may be mentioned Haswell's hydraulic hammer. It consists of a large vertical cylinder hydraulic press, with its ram acting downwards against a table, representing the anvil. The ram is lifted by the piston of a smaller press, with which it is connected by cross arms and side rods placed overhead. The water driven out of the large cylinder as the ram rises is returned to a vertical cylinder or accumulator, also containing a piston, to whose upper face steam can be admitted. This arrangement is used to obtain speed in moving the ram when not actually working, or while the resistance of the pile is inconsiderable. When greater pressure is wanted, a valve, connecting the press with the speed piston is shut, and the ordinary hydraulic press pumps, which are driven by a large direct-acting horizontal steam engine, are brought into action. In this way, by reserving the press pump for the heavier portion of the work, the machine may be driven nearly as quickly as a steam hammer, and owing to the substitution of an intense slow pressure, for the percussive impact of the hammer, massive foundations are not required.

Rolling Mills. These are now generally used in the production of finished or merchant iron, in preference to the hammer, which is mainly confined to the old open fire forges of Sweden and Germany. In its simplest form, a rolling mill consists of two cast-iron cylinders, placed with their axes horizontally one above the other, and connected by spur gearing, so as to revolve at the same velocity when set in motion. The surface of the rolls may be either smooth, as is the case in plate mills, or grooved into various patterns in those used for the production of merchant bars. In the latter case the groove on either roll corresponds to half the section, the two together forming an aperture or rotating die corresponding to the shape required. The reduction in size of the bloom is effected by regulating the vertical distance between the two rolls, by the use of grooves diminishing regularly in size, or by a combination of both methods. Fig. 32 is a generalised elevation of a single pair of rolls, with both angular and flat

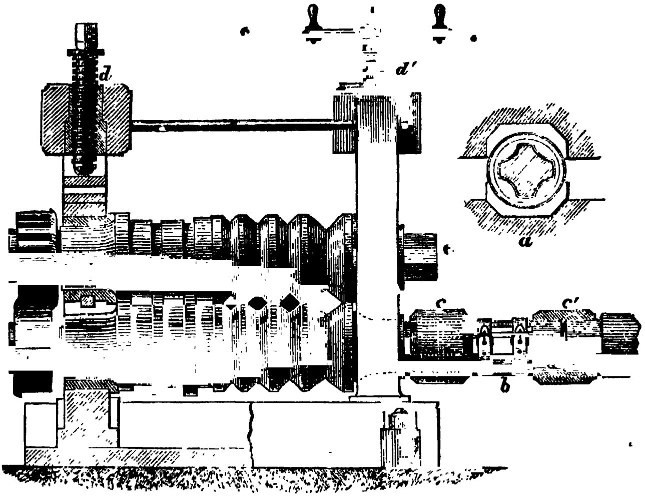


Fig. 32.—Rolling mill.

grooves, a combination which is not actually used in practice, but has been adopted here to avoid the employment of a second figure.

The journals or necks of the rolls run on brass bearings, which are supported in strong cast-iron frames or *housings*. In Fig. 32 one of these is shown in front elevation, and the other in section. The motion is usually communicated by the lower roll, and transmitted to the upper one by a pair of spur-gearing wheels, which are placed either on the rolls themselves, as in the figure, or are carried by a special pair of housings. When two or more pairs of rolls are connected into one system by couplings, and driven by the same motor, they are called a *mill* or *train*. The first pair of the train are generally known as the *roughing rolls*, and the following ones as the *finishing rolls*. The latter have smooth surfaces, but the former, especially in puddle-bar trains, are often roughened, in order to get a better hold on the bloom at its entry. The first pair are also called the blooming rolls, as the work done by them is chiefly confined to welding the bars composing the pile, while the finishing pair is mainly employed to draw out the pile so compacted.

As the direction of rotation of the rolls is constant under ordinary circumstances, it is necessary, after the bar has passed through one groove, to return it by lifting it over the top roll, in order to bring it into position to pass through the next smaller one, and so on in succession. This may be easily done with blooms of small size, but is attended with considerable difficulty when it is required to handle large masses of iron, and in any case gives rise to a certain loss of time, and consequent waste of iron by scaling, from exposure to the atmosphere in a highly heated condition for a longer time than is absolutely required. Various contrivances have been introduced in order to roll at greater speed; the most approved principle being the use of two or more pairs compounded into one, as, for example, placing two or three pairs in advance of each other, or passing the bloom alternately through the grooves of two mills moving in opposite directions; by receiving the bar on a carriage which is rapidly driven from one to the other by steam power; or finally, by the use of a combination of three rolls placed one above another in the same housing, forming the so-called *three-high train*, which is driven from the middle, the central roll gearing forward with the lower, and back with the upper one, or the reverse, so that the bar, instead of being rolled only one way, is passed backwards and forwards by entering it between the grooves of the middle and upper and middle and lower rolls alternately.

Very heavy mills, such as are used for armour plates, require to be reversed at each passage of the pile; this can be the more readily done as they are driven at a comparatively low speed. The transmission of the power in rolling mills, especially those of large size, is usually effected by toothed gearing. Smaller trains are sometimes driven by straps, an arrangement which may be conveniently adopted when each mill has a separate engine. As the rolls, when at work, are subjected to sudden and great variations in torsional strain, it is customary to make the couplings uniting the different members of the train of less resisting power than the necks of the rolls, the joints being arranged at the same time so as to allow a certain amount of independent motion. The arrangement usually adopted for this purpose is shown in Fig. 32, where the bottom roll is supposed to be connected with that of another pair in the same plane on the right-hand side. The necks are continued beyond their bearings for a short distance, but with a smaller diameter, the section being further reduced by four concave grooves or flutes, as shown in the end view at *a*. These are united by a loose piece of similar form, known as the breaking shaft or spindle, *c b*, which is secured by two loose collars, *c c*, overlapping the joints. The collars are prevented from slipping by four wooden stops placed on the flutes of the intermediate shaft, and secured by leather straps. In the event of the rolls being brought up suddenly by the resistance of the pile, the strain is taken by the breaking shaft, which, being the weakest part of the train, gives way, and saves the rolls from fracture. In some instances the breaking shaft is further reduced in area by making a deep semicircular groove round it in the middle.

In rolling bars of small section, which on account of their flexibility are liable to be bent and distorted, it is necessary to keep the end straight in entering the grooves. For this purpose it is usual to attach parallel guides with plain jaws or friction rollers to the tables or aprons of such mills, which are then known as guide mills or trains.

In compound mills with three rolls, the lifting of large piles from the lower to the upper level is attended with considerable labour, unless it be done by special mechanical appliances. The usual method adopted is to make the feed plates or tables movable upon vertical guides, suspending them so as to travel freely by counterbalance weights passing over guide pulleys. The lifting may be effected either by a vibrating lever receiving motion from a rotating shaft; or more simply by a single-acting steam or water-pressure engine placed above the rolls, and connected to the tables by a cross bar and side rods. The pile, after passing a groove in the lower part, is lifted by the action of the steam or other mechanism employed, and after returning through the upper one, drops the table by its unbalanced weight to the lower level, and so on, rising and falling alternately, until the section is sufficiently reduced.

The same kind of arrangement may also be used in heavy plate mills. The pile, after passing between the rolls, need only be deposited on the top of the upper one, as the friction between the two surfaces due to the weight will be sufficient to return the pile to the former position, taking advantage of the fact that the surface above the horizontal median plane of the roll travels in the reverse direction to that below it.

The set, or distance between the top and bottom rolls, is adjusted by means of screws (*d d′*, Fig. 32) acting, either directly or by a cross bar, upon the bearings of the frames. Each screw is provided with a graduated head, in order that in altering the level, either end of the roll may be shifted equally. In rolling bars of irregular section, such as rails, for instance, the adjustment is only necessary in order to bring out the finished product to the proper weight, and, when once made, no alteration

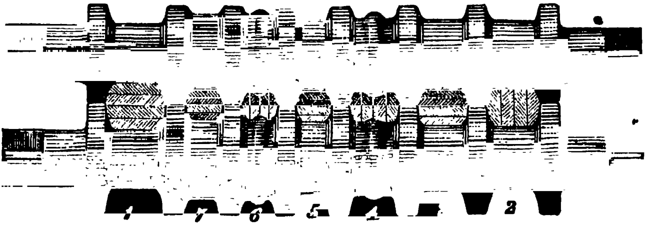


Fig. 33.—Rail mill roughing rolls.

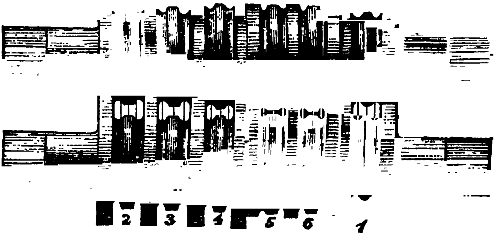


Fig. 34.—Rail mill finishing rolls.

is necessary as long as the mill is kept on the same work, the progressive reduction in the section of the pile being effected by passing it through grooves of continually diminishing area In order to prevent lamination between the bars composing the pile, and to render the welding as uniform as possible, it is passed through with the joints flat and edgeways alternately, in the manner indicated by the horizontal and vertical lines in Figs. 33, 34, which represent the section of both blooming and finishing rolls in a mill making double-headed rails. The numbers in the grooves refer to the order in which they are used.

In plate mills which have no grooves the distance between the rolls must be diminished each time that the pile is passed through. The top roll must also be supported in order to prevent its falling upon the lower one when it is no longer kept up by the pile. This is usually done by carrying the lower bearing of the top roll on a vertical forked rod, whose lower end is in connection with a counterbalance weight sufficient to prevent the roll from falling.

Great accuracy may be obtained in the adjustment of the rolls by attaching spur wheels to the heads of the setting screws, which may then be moved through equal spaces by a third wheel placed between them. In Ramsbottom's system of adjustment, adopted at Crewe, the shaft of the central pinion carries a double spiral barrel with two chains, one of which, passing over guide pulleys, is connected with the ram of a water-pressure engine, and the other coiling in the opposite direction with a counterpoise weight. The rolls are brought together by the pull of the chain from the engine, and separated by the counterpoise acting in a similar manner upon the other chain.

Compound or universal rolling mills consist of a combination of a vertical with an ordinary horizontal pair of plain rolls, so that the pile may be compressed equally in both directions, edgeways and flatways, at once. A combination of this kind, known as While's mill, has been advantageously adopted for blooming rail piles in South Wales. The horizontal rolls are driven in the usual way from below, the vertical pair being connected with them by an intermediate shaft, carrying a mitre-wheel gearing into a wheel upon one of the vertical rolls. The machine is driven at a very low speed, making only five revolutions per minute, so that the pile is subjected to a powerful and long-continued pressure, as compared with the usual system of blooming in the first grooves of the roughing pair in an ordinary train, making from 80 to 100 revolutions per minute. Mills of this class may also be used in the production of bars of plain rectangular sections of a great variety of dimensions by simple adjustment of the rolls, instead of requiring a special pair of grooves for each size, as is ordinarily the case.

Fig. 35 represents the arrangement of the rolls and methods of adjustment in one of the earlier forms of universal mill. In order to simplify the drawing, the whole of the driving mechanism is omitted. The vertical rolls are adjusted by the central sliding pinion on either side, which acts on the setting screws. The bearings are supported upon horizontal guide bars placed between the housings. In the newer forms of this mill only one of the vertical rolls is made movable.

In rolling taper iron, such as the tongues of railway switches, the setting screws are provided with lifting gear, so that the distance between the rolls may be continually and uniformly varied during the final passage of the bars. In the first instance, the rolls are screwed down to the proper distance for producing the thinnest section required, and the pressure is then relieved either by a train of gearing wheels, working pinions on the heads of the screws, or by allowing the upward pressure of the iron passing through the mill to lift the roll. In the latter plan, in use at the Mersey Steel and Iron Works, the pressure is exerted against a solid plunger working in a cylinder filled with water, and provided with a small discharge passage, stopped by a conical plug valve. As long as the valve is closed the water within the cylinder, from

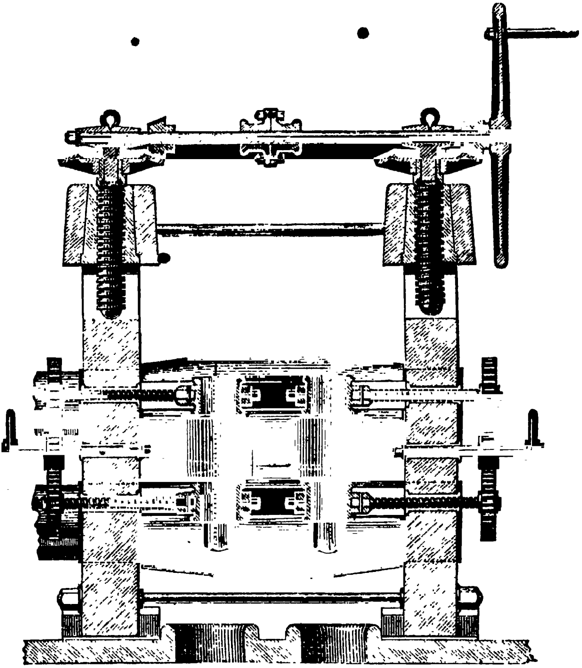


Fig. 35.—Universal rolling mill.

its incompressibility, acts like a solid body, and keeps the rolls together; but when the passage is opened, the pressure from below drives the plunger upwards and expels the water, thereby relieving the bearings of the top roll, which is then free to rise, the rate of its upward motion being regulated by the aperture presented for the efflux of water from the cylinder.

The finishing rolls of plate mills are cast with strongly-chilled surfaces, which are afterwards turned and polished, the necks and other portions being formed in sand moulds.

The rolls of rolling mills are subjected to great heat when at work, from the direct contact of glowing iron, as well as from its friction in passing through the grooves. In almost all cases they are cooled with water, which is led through a gutter above the framing, and distributed in small streams over the working surfaces and necks continuously.

The size and speed of rolling mills vary within very wide limits, according to the character of the work done. Thus reversing mills for heavy plates may make from 25 to 30 revolutions per minute, while small mills rolling wire are driven at from 500 to 600 revolutions in the same time.

In Staffordshire the puddled bar train usually includes two pairs of rolls, from 18 to 20 inches in diameter, and from 3½ to 5 feet in length between the bearings. The grooves of the roughing pair are of a curved or Gothic form, as in the right half of Fig. 32, giving a rough square to the bloom. Those of the finishing pair are rectangular, like those on the left side of Fig. 32, and capable of rolling flat bars from 2½ to 7 inches in breadth, and from half an inch to 2 inches in thickness. Sometimes a third pair is added for rolling slabs from 7 to 15 inches wide, which are used as covering plates for piles intended for making plates.

A mill of the above dimensions serves from sixteen to twenty furnaces. For ordinary-sized merchant bars, the diameter of the rolls is from 12 to 16 inches, and the length from 4 to 6 feet for the roughing, and from 3 to 3½ feet for the finishing pair. The number of revolutions is from 60 to 75 per minute, according to the size of the work.

In South Wales the rolls used in blooming rail piles are from 20 to 24 inches in diameter, and from 5 to 6 feet long. When they are worked as reversing rolls the speed does not exceed from 25 to 30 revolutions per minute; but compound (three-high) mills may be driven much faster. The finishing train makes from 80 to 100 revolutions per minute.

Plate mills are usually made with three pairs of rolls. The first pair are grooved like those of a bar mill for blooming the pile; the second are the roughing pair proper; while those of the third, or finishing pair, are cast with chilled surfaces, and are highly polished. The ordinary sizes are from 5 to 6 feet long, and from 20 to 24 inches in diameter. The working speed varies from 25 to 30 revolutions per minute for heavy, and from 30 to 40 for light plates.

Shears are used for cutting up puddled and other bars into lengths for piling, and also for trimming up the rough edges and ends of finished plates, bars, and sheets. For the former purpose, some form of lever shears, having one fixed and one vibrating jaw, the latter forming one arm of a straight or bent lever, moved by a crank or eccentric, is generally used.

Fig. 36 is an example of a heavy shearing machine used at Dowlais, in South Wales, for cutting up puddled bars into lengths for piling.

When it is required to take a cut of considerable length, guillotine shears, with a diagonal-edged knife which moves vertically between parallel guides, are often used, especially in boiler and other plate work. These are generally machines requiring considerable power, and are driven by a steam engine attached to the same framing. Rails and other thick bars are finished by sawing off the rough or crop ends, and filing down the marks left by the saw while still hot from the rolls. The circular saws used for this purpose are between 3½ and 4½ feet in diameter, and are driven either by belts, or, in some instances, by direct-acting steam turbines placed on the same shaft. The number of revolutions varies between 900 and 1,300 per minute.

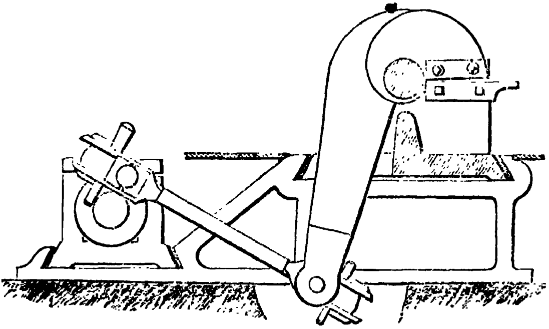


Fig. 36.—Cropping shear, Dowlais (Turner).

In the slitting mill the rolls are replaced by spindles carrying a series of steel discs, fixed a certain distance apart by stops. The discs on one spindle interlock with those on the other, forming a rotary shearing machine, with several pairs of blunt-edged cutters. When a thin, flat bar of iron is passed through in the same manner as in an ordinary rolling mill, it is divided by the blades into thin rods of rectangular section, which are delivered in a very crooked condition, being bent and distorted by the pressure of the blades. These, when straightened by hand, are made up into bundles for the use of the nail forges, and are known as *slit* or *nail rods*.

CHAPTER XVII

REHEATING AND WELDING.

THE rough bars or slabs of malleable iron, obtained in the processes of puddling and shingling, require to be subjected to further treatment in order to produce finished or merchant iron. For this purpose they are cut into short lengths, which are made into nearly cubical packets, or *piles*, and subjected to a further consolidation by hammering and rolling at a welding heat, until a bar with a uniformly smooth surface, free from cracks or flaws, is obtained.

The operation of reheating may be performed in several different ways, as, for example, in the open hearth, in direct contact with the fuel—a method that, as has already been stated, is commonly practised in making malleable iron in the hearth finery; in the hollow fire, immediately above the fuel, but without touching it, used in the South Wales forges; and, finally, in the reverberatory furnace, which is the plan most generally adopted at present.

The reheating furnace, Fig. 37, also known as the *balling* or *mill* furnace, is in external appearance not unlike that used in puddling, being cased with cast-iron plates in a similar manner. The principal difference is in the proportion between the surface of the fire grate and that of the bed, which is less than is the case in the puddling furnace, as, although a higher temperature is requisite, it is less subject to fluctuations, being maintained as uniform as possible. The arch of the roof, except in special cases, is comparatively low; and the bed, which is made of sand consolidated by pressure when in a moistened condition, slopes from the fire-bridge uniformly towards the flue, in order to allow the slag or cinder formed by the combination of the sand with the scale on the surface of the iron to run off freely towards the bottom of the stack, where it is let out of the furnace. This, like most of the other slags produced under similar circumstances, is in composition essentially a tribasic silicate of protoxide of iron, and is distinguished by the name of *flue cinder* from that of puddling furnace, or *tap cinder*, the former flowing constantly, while the latter is only removed from the furnace at intervals. A small fire is usually placed in front of the stack both in reheating and puddling furnaces, in order to prevent the cinder from cooling and becoming solid in the tap hole.

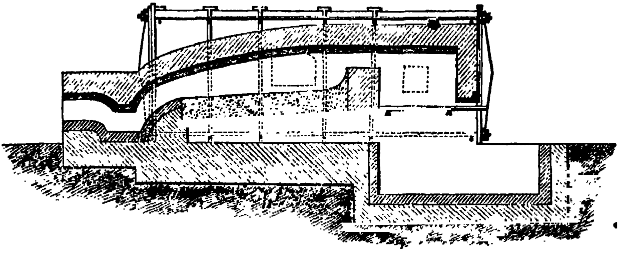


Fig. 37.—Reheating or balling furnace.

Fig. 37 is a longitudinal section of a reheating furnace, such as is used for bars of ordinary sizes, which are finished from the pile at a single heat. The bed is made of fire-brick, covered with a thick coating of sand. In other respects it is very similar in construction to the puddling furnace. In order to prevent the access of air to the bed, it is necessary to keep the fire grate thickly covered with fuel, and the door must be well stopped for the same reason.

In reheating small sizes of iron, it is advantageous to use a furnace with a small hearth and large grate, so as to be able to bring up the piles rapidly to a welding heat, in order to prevent the loss by oxidation consequent upon unnecessary exposure. When the dimensions of the pile are such as to require several passages through the mill in order to reduce it to the proper section, it is often necessary to subject it to a second heating; for this purpose, furnaces of special construction are used, corresponding in dimensions to the form of the pile at the end of the first heat. When the bed is of a large size, as, for instance, in the furnaces used for reheating unfinished plates, a second fireplace is placed at the flue end, with its axis at right angles to the principal one. This class of furnace is used in reheating long and heavy bars, and also in armour-plate mills.

Piling for Merchant Iron. The amount of work put into bar iron varies with the quality. For the commoner kinds, puddled bars, or No. 1 iron, cut into lengths, are piled, and when brought to a welding heat are rolled off, either with or without first being worked into a bloom under the hammer. More usually, however, the iron of second rolling, or No. 2, is employed as the top and bottom plates of the piles, when making finished, No. 3, or *best* iron. Beyond this, if further piled and welded, the iron is distinguished as *best best* and *treble best*, according to the number of heatings and weldings to which it has been subjected. The harder and more granular kinds of iron, such as that used for tires in Yorkshire, are worked almost exclusively under the hammer, the rolling mill being only used in giving the proper figure to the bar at the finishing stage.

The covering slabs for the tops and bottoms of rail piles are sometimes made by doubling and welding two puddled blooms together under the hammer, which are then reheated and rolled to the proper size without having first passed through the state of puddled bars. The use of single plates for the outsides of piles is necessary in order to get a clean surface, as butt joints do not weld properly unless they are covered. In all cases the ends of the bars forming the pile must be cut square, and all the surfaces in contact must be as clear as possible from scale and rust.

Piles for bars should be made as thick and square as can be done consistently with the form of the blooming grooves of the mill, in order that the iron may be subjected to great longitudinal extension. The length will of course depend upon the weight of finished bar required.

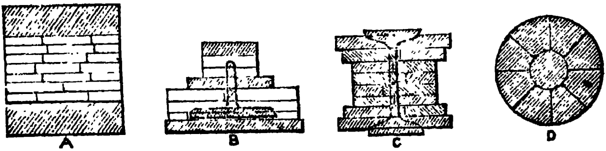


Fig. 38.—Sections of piles for finished iron.

Fig. 38 shows the arrangement of the various qualities of bars and slabs in pile for different kinds of bar iron. The darker-shaded parts indicate slabs of reworked No. 2 iron, scrap bars, or similar qualities, the lighter parts being puddled bars. A is one out of many kinds of pile adopted in the manufacture of rails. B and C are Belgian piles for T and girder iron, the finished sections being given in the centre to the same scale. D is Beattie's system of piling or faggoting adopted for railway axles. It consists of a ring, built up of several segments, arranged round a central circular bar. The bars composing the piles are kept together by bands of wire before they are placed in the heating furnace.

The following example gives the details of manipulation in rolling bars of different sizes followed in a South Staffordshire forge in the year 1861:—For bars of 1 inch square the pile was made up of 6 bars, each three-quarters of an inch thick, and 4 inches wide, the top and bottom plates being of doubled blooms, while the intermediate ones were ordinary puddled bars. The length of the pile was 18 inches, and its weight 100 lbs.

Two heating furnaces were used, each containing a charge of eighteen piles, which, when at a proper welding heat, were passed eleven times through the rolls, the grooves being arranged as follows:—first, two of rectangular section, then five Gothic, and, finally, four square finishers.

The work done by the two furnaces in twelve hours amounted to 9 tons (long weight) of finished bars. The loss on the weight of the piles was about 15 per cent., an amount made up of 5 to 6 per cent. caused by oxidation in the furnace, and the remainder, 9 or 10 per cent., in crop ends and waste in rolling.

The consumption of coal was from 50 to 55 per cent. of the weight of the finished bars. The time occupied in rolling a single heat was from thirty to thirty-five minutes.

In making round bars of 4 inches in diameter and 16 feet long, the pile was 10 inches wide, 11½ inches high, and 6 feet long. The top and bottom were each composed of three thicknesses of puddled scrap bars hammered and rolled, while the centre was made up of five layers of ordinary puddled bars. Three heating furnaces were used, each holding a single pile, which required from two and a half to three hours to bring it to a welding heat. In rolling, the pile was passed through eleven times, being turned a quarter round each time, so as to bring the joints into the vertical and horizontal positions alternately. The loss in the process amounted to between 30 and 32 per cent., out of which about two-thirds, or 21 per cent., was accounted for in the crop ends. The coal burnt amounted to 65 per cent. of the weight of the finished bars.

In making small sizes of merchant iron, such as small round or square bars or hoops, the pile, after being partially drawn to a square bar, is cut into lengths known as *billets*, which are afterwards finished separately. The work is done very quickly, although, owing to the small size of the billets, the daily produce expressed in weight is not very large. When the billets are finished in one heat, the consumption of coal is from 11 to 12 cwt. per ton; but when two heats are required, the amount is increased to 20 cwt., or equal weights with the bars produced.

In South Wales the ordinary weight of the pile for rails is about 15 cwt., long weight, four being placed in the furnace at once; the whole of these are rolled to blooms in a triple mill in five minutes, each passing through four times alternately flat and edgeways.

The second heat is effected in half an hour, the furnace being similarly charged, when the blooms are passed through the rail mill nine times, the whole operation being performed in one minute. In order to keep the mill constantly at work, fourteen heating furnaces are required, ten for the first, and four for the second heat. The loss, including the crop ends, is about 20 per cent. on the weight of the pile. In some cases these are passed through a special flattening mill, in order to reduce them to a rectangular figure for greater convenience in piling, but more generally they are converted into slabs in the same manner as ordinary puddled bars. The special application of crop ends to the manufacture of iron free from phosphorus, by Parry's process, has been previously noticed at p. 285.

The total amount of coal consumed in the manufacture of iron from the ore to the finished bars of common, or No. 2 quality, may be taken at five times the weight of the latter, with an increase of about 10 cwt. per ton for every additional heat.

Plates and sheets are divided into classes according to thickness, the former term being restricted to all sizes above No. 4 of the Birmingham wire gauge, corresponding to a thickness of 0·238 inch. Sheet iron is further classified into three divisions, as follows:—

Singles,	including	from No. 4	to No. 20	gauge or	0·238	to 0·035	in. thick.
Doubles	,,	,, 20	,, 25	,,	0·035	·020	,,
Trebles or lattens	,,	,, 25	,, 27	,,	0·020	0·016	,,

The piles for the heavier classes of plates are built up of layers of bars, placed alternately across each other, instead of having their longer sides parallel, as is the case with ordinary bar iron. The covering slabs, or top and bottom plates, are flat bars, from 9 to 12 or 14 inches wide, and from 1 inch to 1½ inches thick, which are made by doubling two puddled blooms under the shingling hammer, and rolling to the proper size at one heat.

For boiler plates measuring 6 feet long, by 3 feet broad, and $\frac{3}{16}$ of an inch thick, weighing about 2¼ cwt. each, the pile is made 20 inches long, 6 to 7 inches high, and 12 inches broad. The whole of the work is done at one heat; the pile is reduced to a roughly-squared bloom by passing it lengthways through three grooves in the blooming rolls, then four times through the plate-roughing rolls in the direction of the breadth, which draws it into a thick-squared plate, and finally, three times lengthways through the finishing rolls. The difference in weight between the finished plate and the rough bars taken for the pile is from 20 to 22 per cent.: this amount includes the waste in reheating and scrap produced in shearing the edges to the proper size. The amount of coal consumed in the reheating furnace is from 14 to 15 cwt. per ton of plates produced.

For the larger sizes of sheets, such as singles of No. 12 gauge, measuring 6 feet in length by 2 feet in breadth, the piles, 20 inches in length, 7 inches in breadth, and 4 inches in height, are made up of the scrap and crop ends produced in making the top and bottom plates, which are three-quarters of an inch thick. The weight corresponding to the above dimensions is about 70 lbs. Nineteen or twenty piles are placed in the heating furnace at once. In passing the blooming rolls, the pile is converted into a bar of double the original length, without any alteration in breadth, and is then cut into two parts, each of which is passed crossways through the roughing rolls, until it is reduced nearly to the breadth required in the finished plate. After passing four times lengthways through the finishing rolls, the two halves of the original bloom are placed one above another, and passed through together three or four times more; they are then nearly cold, and are immediately taken to the annealing furnace, where they are subjected to a low heat to soften them, after which they are sheared to the proper size and finished.

The rolling of thinner sheets is very similar to that last described, except that the piles are of a much simpler character, on account of their smaller weight, consisting simply of three or four plain flat bars. For doubles of 20 to 24 gauge, the rough bar is cut in two, and the halves are passed through the plate rolls, first separately, and then together, as in the preceding instance. The rough sheets are placed together in bundles of four in the annealing furnace, and after heating and passing through the finishing rolls, are subjected to a second heat in the same furnace before being sheared.

Lattens or trebles of No. 27 gauge, measuring 54 inches in length, by 28 inches in breadth, and weighing 5½ to 6 lbs. per sheet, are made from roughed-down slabs 4 inches broad, and half or three-quarters of an inch thick, cut into lengths of about 18 inches. These lengths are heated to redness, and passed separately through the roughing rolls, and two or three times through the finishers, after which they are doubled, and the rolling is continued until they have cooled to a dull red heat, the original blank having by this time become extended to a sheet measuring 32 inches by 24.

In rolling after the first annealing heat, four plates are taken together, and in finishing, which follows final or second annealing heat, eight thicknesses are passed through at the same time. Owing to the number of reheatings, and the large amount of surface of the finished work as compared with its weight, the loss and consumption of materials are comparatively large. For the production of 1 ton of sheets sheared to the proper size, 25 cwt. of coal are required, and 25 or 26 cwt. of rough bars. Out of the waste of 5 or 6 cwt. on the latter quantity, about 4 cwt. are accounted for in the shearings and crop ends, produced at different stages of the process. No great amount of scaling takes place, owing to the comparatively low temperature at which the work is done.

Thin sheet iron or *black plate*, intended for tinning, is made in a similar manner to that last described, the unfinished work being doubled after every heating, so that at last as many as sixteen thicknesses are passed through the mill together. When reduced to the proper dimensions, the plates are brought to a bright metallic surface by pickling in weak sulphuric acid. A final polish is given by cold rolling, after which the plates or sheets are ready for tinning.

Very heavy plates, such as those used for ships' armour, are made either by hammering or rolling alone, or by a combination of both methods. In the first case, the original material is best scrap iron, made into piles weighing from 1 to 1½ cwt. each, which are balled in threes or fours into a slab at one heat. According to the thickness of the plate required, these slabs are reheated either alone or doubled, and reduced at a second forging to an oblong slab, somewhat thicker than the finished plate, with two squared and two chamfered edges. In finishing, two pieces are joined to form a section of a plate of the required breadth, by joining the tapered edges together on the shorter sides, and finally, the length is made up by adding as many pairs as may be necessary. For convenience of manipulation, a staff, or *porter bar*, with a capstan-headed ring fixed to it, is welded to one of the unfinished plates, in order that it may readily be turned on the anvil, as is usual in all large forgings. The final forging, to reduce the plate to the proper thickness, is effected at a moderate red heat, water being constantly thrown on the surface to clean it from scale. When finished, it is annealed by heating to redness and slow cooling. By the use of tapered edges the surfaces of contact cross the finished plate obliquely.

Rolled armour plates are put together as follows:—The balls from the puddling furnace are shingled and rolled to slabs about 12 inches broad, 30 inches long, and 1 inch thick. Five or six of these slabs are in a second heat rolled to a slab about 4 feet square. At the third piling, five or six slabs of the second heat are welded and rolled into a plate 8 feet long, 4½ feet broad, and 2½ inches thick, weighing rather more than 30 cwt., and made up of between twenty-five and thirty-six original inch slabs of No. 1 iron.

The edges of the plates require to be kept as true as possible, so that a certain amount of shearing may be necessary at the intermediate step of the process. For the finished plates of 4½ or 5½ inches in thickness, four of the large 30-cwt. plates are piled together, and reheated in a furnace having a fireplace at either end. In order that the whole pile may be uniformly heated, the lower surface, instead of touching the bed of the furnace, is supported on six small pillars of brickwork, so as to allow the flame to pass below it. The door of the furnace is placed parallel to the axis of the rolling mill, and the pile, when sufficiently heated, is drawn forward with tongs, and received on a truck, which runs upon a railway directly to the rolls. A similar truck is placed on the opposite side of the mill, and the pile is passed forwards and backwards by reversing the rolls until it is reduced to the proper thickness. The surfaces of these trucks incline towards the rolls, or are provided with friction rollers, so that the pile may be easily pushed between them by hand, the force of the rolls being sufficient to drive it up the incline of the receiving surface. The plate, after leaving the rolls, while still hot, is placed upon a cast-iron table, and rendered perfectly smooth and flat by passing a roller weighing 7 tons over it. When cold, the rough edges are dressed up square on a planing machine. Armour plates are now regularly made of all thicknesses up to 12 inches. One of that thickness 14 feet long and 5¼ feet broad, weighs 15 tons 7 cwt.

The composite character of rolled bar iron made from large piles may be rendered evident by etching a polished transverse section with weak sulphuric acid, when a series of irregular curved lines will be developed, corresponding to the original surfaces of contact of the component slabs. Uniformity in the character of the lines is a sign of good welding; but black irregular patches indicate that the cinder has not been entirely expelled.

Application of the Waste Heat of Puddling and Reheating Furnaces. Under ordinary circumstances, the heat developed by the coal burnt in the fireplaces of these furnaces is but imperfectly utilised, as the flame leaving the hearth at the welding temperature of iron escapes into the atmosphere at the top of the stack, carrying away an amount of heat greatly in excess of that necessary to keep up the draught of air through the fire. In order to economise some portion of this heat, various methods have been adopted of interposing cooling substances by passing the flame through the flues of steam boilers or blast-heating stoves. The former method is used for furnaces fired with solid fuel, while the latter is more especially adopted for gas furnaces. A more complete method than either is the so-called regenerative gas furnace of Siemens, where the waste heat is applied in raising both the gases used as fuel and the air for burning them to a high temperature previously to their arrival at the point of combustion, by which means a very high and uniform heat is attainable.

The commonest form of boiler used for raising steam by the waste heat of forge and mill furnaces is a vertical cylinder with a hemispherical dome. The flame either passes round the outside, or through a central flue connected with the external shell by a series of horizontal tubes. Generally two furnaces are in connection with the same boiler. A more perfect method, but one that can only be adopted in large works, is to lead the flame from a considerable number of furnaces into a single horizontal flue of proportionately large section, which carries it through the heating tubes of the boiler. The resistance opposed by the interposed obstacles is overcome by the draught of a tall chimney. In this way there is no chance of the working either of the furnaces or boilers being checked by alternations of temperature, as may sometimes be the case when only one or two furnaces are used with a separate boiler.

In Hungary and Austria different combinations of reheating and puddling furnaces fired with gaseous fuel have been recently adopted. At Rhonitz a furnace of this kind has an ordinary gas generating chamber for burning wood, combined with three hearths placed in one longitudinal series. The first of these is intended for reheating blooms and billets of iron. It receives the full stream of the heated gases—which contain no uncombined oxygen—from the generator before they reach the point of final combustion at the top blast jets, which are placed in the usual position above the fire-bridge of the puddling hearth. The third bed is used for warming up the pig iron before melting it in the puddling process. Lastly, the flame, before entering the stack, is carried round a blast-heating arrangement consisting of two vertical cast-iron pipes, divided by central partitions, which raises the air employed in the top blast to a temperature of 200°.

A furnace of this class is found to be productive of a certain economy in iron, 129½ lbs. of pig iron being sufficient to produce 100 lbs. of billets instead of 134 lbs., as was the case when the puddling and reheating were effected in separate furnaces. The saving of fuel is, however, very considerable, 7·9 cubic feet of wood being now found sufficient when 18 cubic feet were formerly required.

A somewhat similar combination to the preceding is applied to the waste heat of an open reheating fire at Reichenau. The hearth is of the usual rectangular form, but is blown with two twyers instead of one. The fuel employed is charcoal. The hood covering the hearth resembles the roof over the fireplace of a reverberatory furnace. The flame, together with a considerable quantity of inflammable gas derived from the incomplete combustion of charcoal dust or braise on the first hearth, is led into the second, or puddling bed, where it meets the second blast, which is heated to about 200°, and is introduced through a line of narrow twyers, extending along the fire-bridge, and inclined at a considerable angle to the direction of the gaseous current. Behind the puddling bed are placed two others, for warming the iron at various stages in the process, which may be distinguished as Nos. III. and IV., and the lower part of the stack contains the blast-heating pipes, which are of the horizontal serpentine form. The different parts of this furnace used are as follows:—The puddled balls from the second bed, after being shingled into blooms, are subjected to a preliminary heat in the fourth, or last, which also serves for heating the pig iron previously to puddling, and are then transferred to the charcoal fire, No. I., where they are brought up to the proper temperature for conversion into puddled slabs or rough bars. The finished iron, which in this case is intended for waggon tires, is produced by reheating the rough bars of the preceding operation in hearth No. III., and drawing them to the proper shape under the hammer. This is said to be a very economical furnace, in spite of its apparent complication. The consumption of materials in the different stages is as follows:—

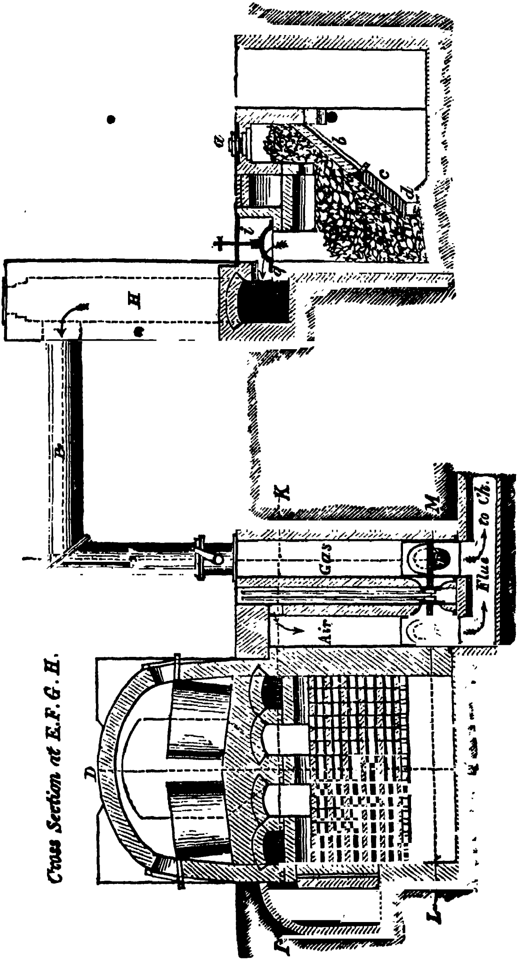
160 lbs. pig iron give 100 lbs. blooms;
114 lbs. blooms ,, 100 lbs. puddled bars;
104 lbs. puddled bars ,, 100 lbs. finished tire iron;

corresponding to a total consumption of 126 lbs. of pig iron and 12 cubic feet of charcoal per 100 lbs. of finished iron.

Siemens' regenerative gas furnace, as applied to puddling, is similar in general character to the cast-steel melting furnace described at p. 358, supposing a puddling chamber to be substituted for that containing the melting pot *a* in Fig. 43. The puddling bed is made of cast-iron plates, surrounded by hollow boxes cooled with water in the usual way; the bridges and flues at either end are exactly similar, so that the current of heated gases may be made to travel in either direction without affecting the working of the furnace. Below the ground level are placed four large vaulted chambers, separated from each other by thick walls, and filled with fire-bricks arranged in cellular piles, similar to those in Cowper's stove, as shown in Fig. 15, p. 170. These, the so-called *regenerators*, are employed to keep back a portion of the heat carried away by the gases after they have done their work in the puddling chamber, and which, in furnaces of the ordinary construction, is lost by allowing the flame to pass directly into the chimney. The heat taken up by the bricks is transferred to the inflammable gases used as fuel, and the air intended for burning them before their admission to the point of actual combustion, by which means a much higher temperature can be obtained than is possible with furnaces of the ordinary form, burning solid fuel on a grate.

In Figs. 39 and 40 (taken from Tomlinson's "Cyclopædia") the principal details of the regenerative furnace are shown as applied to plate-glass melting, and although intended for a different purpose from that at present under consideration, will be sufficient to illustrate the principle of the invention, the whole of the construction being generally similar, with the exception of course of the chamber containing the melting pots D, which we must imagine to be replaced by a puddling furnace of the form indicated in the preceding paragraph.

The gas producer, Fig. 39, is a large chamber, of



triangular section, capable of holding several tons of fuel, small coal or slack being usually employed. The charging is effected through the stoppered hole *a*. The coal travels slowly down the inclined wall *b*, becoming gradually heated and parting with its volatile matters until it reaches the step grate *c*. This is formed of a number of broad thin-edged bars, overlapping each other like the laths of a Venetian blind, so as to leave only a series of narrow spaces between them for the admission of air. The combustion goes on very slowly, the small amount of carbonic acid produced at the bars being immediately decomposed by the thick column of incandescent fuel above, so that the contents of the chamber are gradually converted into inflammable gas, chiefly carbonic oxide, which, diluted with the nitrogen of the air remaining after combustion, is subsequently employed as fuel in the puddling furnaces. At one time a certain amount of steam was introduced from a perforated pipe at *d*, which was filled with water and heated by the spare heat of the fire. The steam, in its passage over the ignited carbon, was decomposed with the formation of carbonic oxide and hydrogen, whereby the calorific value of the gas was considerably increased. This part of the process has since been given up, owing to the difficulty of regulating the amount of steam injected, and the great absorption of heat caused by the decomposition was found to give rise to an injurious local cooling unless the operation was very carefully watched.

The gas evolved from the generator passes through the valve *g* into the stack H, whence it issues at a temperature of about 200°. In traversing the horizontal iron pipe P, it loses about one-half of its heat, so that its density is sufficiently increased in the descending pipe P′ to establish a continuous draught from the gas produced towards the furnace without the use of a special chimney.

The position of the two generators $f'''\,f''''$ is shown in the half plan at L M in Fig. 40. The other two,

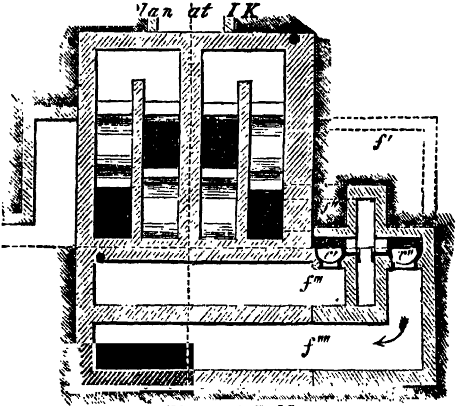


Fig. 40.—Siemens' furnace. Plan of flues.

$f'\,f''$, are similarly placed, as indicated by the dotted lines. The arrangement of the bricks will be understood from the section in Fig. 39, as well as that already given in Fig. 15. They are worked in pairs, two being heated by the waste flame, while others are giving up their heat to the cold gases and air. Owing to the large amount of surface presented by the bricks, the absorption of the surplus is effected with comparative rapidity, and the temperature of the current escaping to the chimney is reduced nearly to the boiling point of water. As soon as the brickwork has attained the proper temperature in two of the chambers, the current is turned into the adjoining pair by reversing the valves $r\ r'$, Fig. 39, and $r'\ r''$, Fig. 40, and the heat accumulated in the brickwork is abstracted by cold air, to pass through one, and gas through the other, until the second pair is heated, and so on, the process being kept up continuously, notwithstanding the intermittent action of the regenerators taken separately.

When applied to puddling iron, a current of heated gas is brought into the furnace by a narrow rectangular chamber, opening into a slit in the body of the fire-bridge. The air comes through a parallel flue behind, and at a higher level, in order that it may, from its specifically greater weight, fall towards the upward stream of gas, and become perfectly mixed. As in all other gas furnaces, the nature of the atmosphere may be perfectly regulated by varying the amount of air introduced. This is a point of great importance in reheating furnaces, where it is necessary to keep out free air as much as possible, in order to prevent the iron from burning to waste.

The regenerative principle has been adopted by Lundin, at Munkforss, in Wermland, for a gas-welding furnace, fired with a very unpromising material, namely, sawdust, containing from 50 to 60 per cent. of water. A condenser containing a series of pipes, terminated with finely-perforated injection roses, adjoins the gas producer, so that the issuing current of gas is immediately brought in contact with a shower of finely-divided water, the jets being arranged to cross each other, and reach every part of the condensing chamber. The temperature is thus reduced from 350° or 400° to 35° or 40°, and nearly the whole of the steam mixed with the gas is condensed, together with the tar, pyroligneous acid, and such other volatile substances produced from the destructive distillation of the sawdust as may be susceptible of condensation by the action of water. In addition to the water jets, a second condensing chamber is used; this is filled with wrought-iron bars, piled like the bricks in the regenerators, which are cooled by a constant flow of water.

The gas issuing from the condenser, after cooling and drying, is said to retain only 4 per cent. of water vapour. Of course a considerable amount of heat is lost by the enforced cooling, and has to be taken up again in the regenerators; but this disadvantage is small as compared with the increased heating power gained by the removal of the water. The regenerators for heating the gas are one-fourth larger in area than those through which the air passes. The consumption of sawdust by this furnace is at the rate of from 11 to 14 cubic feet for each 100 lbs. of finished iron.

According to Siemens' calculation, the surface necessary in the regenerators is six square feet, to take up the heat produced by the combustion of one pound of coal per hour, corresponding to 510 square feet for a consumption of 10 cwt in the day of 24 hours. The cubic capacity of the regenerators for this amount of surface is 122 cubic feet; and, as the bricks occupy half the space, the volume of the latter is 61 cubic feet, and their specific gravity 1·8 making a weight of 1,715 lb. for each chamber. As the specific heat of bricks is 0·21, or the calorific capacity 153·4, they may be considered as equivalent, thermally, to 1,260 lb. of gas, or 1,128 lb. of air. As, however, it is necessary, for the complete combustion of the gases, to admit an amount of air not less than 20 per cent. in excess of the theoretical quantity, the air regenerators are made larger than those used for heating the gas in the proportion of 7 to 4 as a maximum. This provision for varying the amount of air, while the composition of the gas remains constant, allows the production of a neutral, oxidising or reducing flame, according to the requirements of the process.

An investigation of the calorific effect of the Siemens' furnace, in regard to the distribution of the heat developed, has been recently published by Krans. He calculates that the amount of heat expended by the indirect consumption of the fuel, *i.e.*, by converting it into carbonic oxide, to be about 31·7 per cent. of the theoretical effect produced by complete combustion.

The work done by the gas burnt in the furnace, taking it as similar in composition to that of the glass-melting furnaces at Saint Gobain, and to be burnt with 20 per cent. excess of air, is as follows :—

Heat lost in the stack	11·31 per cent.	23·86
" " in the regenerator by transmission . . .	12·55 "	
" employed in raising iron to the welding temperature taken at 1600°	15·48 "	76·14
" remaining in furnace and transmitted through walls . .	60·66 "	
	100·00	100·00

Of the total heating effect derivable from the gases, therefore, 76·14 per cent. is utilised, and 23·86 per cent. lost, or rather, not applied directly to the work. Taking into account the loss of 31·71 per cent. incurred in the gas generator, we have, as the total duty of the coal burnt, 52 per cent., and the loss 48 per cent. When it is considered that these figures represent a result many times more favourable, as regards utilisation of heat, than that of the ordinary system of burning coals on the grate of a reverbatory furnace, we may realise to some extent the enormous loss in the stack of an ordinary puddling or heating furnace.

At Weilersbach, near Trier, pig, smelted with a mixture of charcoal and coke, is treated in Siemens' puddling furnace, with the following result:—The charge, weighing 4 cwt., is worked under the cinder, the boiling being allowed to progress for some time without stirring, by which means a pasty mass of white iron, containing only combined carbon, is formed on the bottom in a condition favourable for being thoroughly and uniformly worked by the subsequent labour of the puddler. As the bed of the furnace is very quickly acted upon, it is necessary to cool it down after the working of each heat, and repair it with a few shovelsful of hammer scale, and, after every second or third, a portion of malleable scrap is added, in order to keep up the necessary covering of slag over the iron bottom. In ordinary work, 10 heats of 4 cwt. are made in the 24 hours. 100·5 lbs. to 106·5lbs. of pig iron is required per 100 lbs. of puddled bars, and the consumption of coal is 85 lbs., or, in the most favourable cases, 70 lbs. With the ordinary furnaces, the quantities are 115 lbs of pig iron and 140 lbs of coal per 100 lbs. of puddled bars; showing a saving of from 7 to 8 per cent. in the waste of iron, and about 50 per cent. in the fuel. At De Wendel's works, on the Moselle, similar results were obtained with the white pig iron of Hayange, in a furnace fitted with a mechanical puddler, and taking charges of 8 cwt. From 14 to 15 heats were made daily, with a consumption of 106 lbs. of pig iron and 70 lbs. of coal per 100 lbs. of puddled bars; but the quality of the latter was not good, the amount of phosphorus retained being greater than in the bars produced in the ordinary furnace. Kosman attributes this to a want of oxidising power in the flame, and to the more acid character of the slag (it contained 15 per cent. of silica, as against 12 per cent. in the ordinary furnace), which worked injuriously by being deficient in peroxide or magnetic oxide of iron, which is well known to be the most potent oxidising agent in the process of puddling, and by its greater fluidity, which prevented the charge being thoroughly worked without a great loss of time. The extreme heat of the furnace is also supposed to be in some degree chargeable with the result, as the affinity of carbon for iron is said to be increased at very high temperatures, which renders the fining difficult, resulting in the production of a steely, imperfectly-refined product, instead of the soft malleable iron required. From this reasoning, therefore, we may be led to the conclusion that the Siemens' furnace can be more advantageously applied in processes where heat alone is required, as, for example, in reheating, or the fusion of steel, than for puddling. At Bolton, the results obtained in this furnace are as follows, according to Siemens:—The yield was at the rate of 20 cwt. 2 qrs. 2 lbs. of pig iron per ton of puddled bar; while, in the ordinary furnace, 22 cwt. 2 qrs. 20 lbs. were required, thus showing a saving, as far as loss of iron is concerned, of about 10½ per cent. The gas furnace worked off eighteen heats per shift of 24 hours, while the ordinary furnace made only twelve in the same time. The exact saving of fuel could not be ascertained, because some reheating furnaces were worked from the same set of gas-producers, but it is estimated at from 40 to 50 per cent. The amount of red ores used for fettling was somewhat increased, but when the furnace was supplied with water bridges this was reduced to the average proportion of 92·6 lbs. per charge, in addition to the ordinary allowance of bulldog, while the yield per charge of 484 lbs. of grey forge pig was increased to 485 lbs. of puddled bar, or a slight gain on the weight instead of the ordinary loss of 12 per cent.

At Monkbridge, near Leeds, the yield of puddled bars was 95 per cent. of the weight of the pig iron charged, while in the ordinary furnace it was only 88 per cent.; in the former case, however, red ore was used to the extent of 1 cwt. per charge of 6 cwt. of grey forge pig, while in the latter only one-third of that quantity was used for the same weight of charge. There was a saving of fuel in the proportion of 16 cwt. to 20 cwt.; but this was only obtained by the use of a better quality of coal in the gas producers than was required in the ordinary furnaces, this being in part due to the gas being employed for reheating and steel melting as well as puddling. The furnace required greater care in its management than the ordinary kind.

CHAPTER XVIII.

METHODS OF PRODUCING STEEL.

Methods of Producing Steel. It has already been stated that steel forms an intermediate link between ordinary cast and malleable iron, and unites in a greater or less degree the properties of both. Its distinguishing characteristic, however, is the power of being hardened or softened at pleasure by sudden or slow cooling from a high temperature.

The following are the principal methods of making steel:—

1. By the Catalan forge, directly from the ore.
2. From pig iron, by fusion and partial oxidation in the hearth finery.
3. From the same metal, by a similar process in the puddling furnace.

4. By exposing bar iron to the action of solid or gaseous carbonaceous matter at a temperature below its melting point. This method is known as conversion by cementation, and the amount of change produced is mainly dependent upon the time employed. When merely a surface coating of steel is required, the process adopted is known as case-hardening; while, on the other hand, if sufficiently long continued, the iron may be completely converted into cast iron.

A process which may be regarded as the reverse of cementation is practised to a certain extent upon cast iron, by exposing it to heat in closed vessels filled with finely-powdered hematite. The surface of the casting is decarburised at the expense of the oxygen of the peroxide of iron, with the production of a malleable coating. This is known as the method of making malleable cast iron.

In the above processes steel is produced without melting, and is converted into bars by hammering and rolling, in a similar manner to that adopted in the manufacture of malleable iron. A more homogeneous product may be obtained by fusion, according to the following methods:—

5. The cemented or blister steel produced in No. 4 is broken up into small pieces and melted in crucibles, with or without fluxes, in quantities of from 60 to 80 lbs. This is the original method of making cast steel introduced by Huntsman, in the neighbourhood of Sheffield, and is still largely used in the same district for the production of the higher class of cutlery and tool steel.

6. By blowing air through molten pig iron until it is wholly or partially decarburised. In the former case the necessary amount of carbon is restored by the

addition of highly-carburised pig, such as spiegeleisen, in small quantity. This is what is known as Bessemer's process.

In addition to the above processes, several new methods of making cast steel have been proposed and adopted to a certain extent, but not generally. The essence of these methods consist in fusing cast iron with oxidising, or wrought iron with carburising additions, or by fusing cast and wrought iron in proper proportions alone, as in the last step of the Bessemer process. The following are some of the more prominent:—

Uchatius' Process. This consists in melting in crucibles granulated pig iron with peroxide of iron, produced from roasted spathic iron ore, and a small quantity of oxide of manganese. By varying the proportions of metal and ore, and especially by the addition of a certain quantity of malleable scrap iron, a softer or milder steel may be obtained.

Obuchow's method of producing cast steel is generally similar to that of Uchatius. White pig iron is fused with malleable iron or steel scrap, with variable additions of magnetic iron ore, titaniferous black sand, such as is obtained in gold-washing, arsenious acid, nitre, and clay, or with arsenious acid and magnetite alone. The operation is conducted as follows:—The scrap iron, magnetic oxide, and clay are placed in a large clay crucible which has been previously brought up nearly to a white heat; the cast iron is then run in melted from a cupola, and the crucible is heated until the contents are perfectly fluid; the remaining ingredients, namely, arsenious acid and nitre, are then added, the whole being well stirred. The steel is cast in closed cast-iron moulds, and the ingots, as soon as they have cooled down to a red heat, are removed, and taken at once to the hammer and tilted.

Price and Nicholson's process consists in melting malleable iron with refined metal, that is, pig iron free from silicon, the relative proportions of the two metals being adjusted according to the character of the steel that it is desired to produce.

Indian cast steel, or *Wootz,* is made from malleable iron cut into small pieces, which are charged in quantities of about 1 lb. weight in clay crucibles, together with about 10 per cent. of dried wood of *Cassia auriculata,* and two or three leaves of *Asclepias gigantea.* The covers of the crucibles are luted on with clay, and when dry, some twenty are heated together in a charcoal hearth for about two hours. On breaking the crucible after fusion, a round cake of steel is obtained, about 1 inch in thickness and 5 inches in diameter, which is perfectly smelted, and usually presents a series of finely-radiating striations on its upper surface. Wootz is extremely hard, containing a large amount of carbon, and requires great care in tempering and forging.

The addition of charcoal or other carbonaceous matter in the fusion of blister steel furnishes a ready method of controlling the hardness of cast steel, and is commonly practised, especially where a proportion of malleable iron is added to the charge. The same effect may be produced by the use of crucibles made of blacklead instead of clay, the carbon required for the conversion of the malleable iron into steel being furnished by the substance of the crucible: the latter modification is said to be largely used by Krupp at Essen, in Westphalia.

In making the so-called *natural steel* in open fires, a method that was formerly practised to a considerable extent in Styria, Westphalia, and other parts of Europe, but which is now being rapidly superseded by more improved processes, the hearth differs from that used in making malleable iron by having less depth, while the twyer is at a lower level and more strongly inclined, as the molten mass is not brought directly before the twyer, but is decarburised under the joint influence of the blast and slag, with an increased expenditure of time and fuel. As a rule, about double the quantity of coal and one-half more time is required to convert a charge of pig iron into steel than would be the case if the same weight was operated upon for malleable iron. The best varieties of pig iron for the purpose are those containing a considerable quantity of carbon, such as spiegeleisen, or the strongly-mottled variety called *blumige floss*, containing flowers or spots of grey upon a white ground. Dark grey pig can be used, but should first be subjected to refining.

In Styria the process is conducted on hearths, with a bottom of charcoal dust about 12 inches thick. The first portion of the charge, weighing 120 lbs., is melted down with a small quantity of cinder, the latter being strewed over the coals, the reheating of the blooms (*masseln*), about ten or twelve in all, from the former operation, going on at the same time. When only two blooms are left, a further addition of pig iron is made to the extent of from 30 to 60 lbs., and the blowing is continued until the hearth is filled to within 1 or 2 inches of the twyer. The fire is then allowed to go down quickly, the slag is tapped through a hole in the front plate into a trough filled with water, and the lump of crude steel remaining in the hearth is allowed to cool, out of contact of the air, by covering it with a shovelful of moistened cinders. In about a quarter or half an hour after stopping the blast, the lump is lifted out of the furnace, and is then divided under the hammer into ten or twelve pieces, which, as has already been stated, are reheated during the fining of the next charge.

The bars drawn under the hammer are hardened by quenching in cold water, and broken, in order to test their quality. They are sorted according to hardness into several classes, distinguished by special names. The best are known as chisel or tool steel, noble steel, and crude steel, below which come a variety of steely irons, used for scythe-making, waggon-wheel tires, and similar purposes. Usually the forges are small, each containing two fires and a hammer, having three water wheels, two for the bellows, and one driving the hammer, which weighs from 5 to 6 cwt., making from 70 to 120 strokes per minute, with a maximum lift of about 2 feet. When small-sized bars or scythes are made in the same forge, a lighter tilt-hammer of 3 or 4 cwt. is generally used. With both fires at work, four men produce about 12 or 15 cwt. of crude steel blooms in sixteen hours. The consumption of charcoal is about 30 cubic feet per cwt. under ordinary conditions, but may be reduced to between 22 and 25 cubic feet by using covered hearths and hot blast. The proportional yield of the different kinds of steel is as follows for every 100 parts of pig iron treated :—

60	parts of	steel of all kinds (crude, noble, and chisel steel).
20	,,	mock, or over-refined steel, containing soft iron.
10	,,	steely iron of different kinds.
10	,,	loss.
100		

The Carinthian process is carried out with much larger quantities of pig iron at one time than the Styrian. The charge, weighing about 5 cwt., is melted down in a hearth some 2 feet square, with an effective depth of from 7 to 9 inches below the twyer. The bottom of the hearth is lined with charcoal dust or brasque in the usual way. The twyer is about 1¼ inches wide, and plunges from 10° to 16°. The charge is kept melted before the blast for three hours, as in the ordinary process of refining, and after removal of the slag, is converted into thin plates by throwing water on the surface, and stripping off the chilled metal in crusts or discs of about 1 or 1½ inch thick. After the fire is made up, the first portion of the bloom obtained in the preceding operation is reheated and hammered—an operation requiring about an hour and a half. A quantity of from 40 to 70 lbs. of pig iron, with a little cinder, is then melted down gradually, and upon this the refined metal of the first operation is added by small quantities at a time, until the whole charge forms a more or less pasty or imperfectly fluid mass (*sauer*) on the hearth bottom, which is broken up with a bar and piled into a heap in the centre. The amount of working depends upon the feel of the iron. If it *dries* too rapidly, fresh pig iron must be added, while in the opposite case of being too fluid, oxidation is promoted by the addition of hammer scale. The upper portion of the mass, being under the influence of the blast, loses its carbon; while the lower part, being in contact with the glowing charcoal lining the hearth remains in the condition of cast iron. After making up the pile, the second portion of the previous bloom is reheated, and when this is finished, the contents of the hearth, having subsided to a uniform level surface, are found to be sufficiently fined to allow the formation of a fresh bloom, which is broken out and divided into two parts for further treatment. The half blooms are again divided, and finally finished into bars, which are hardened, broken, and selected in the same way as in Styria.

It will be seen that the same hearth is, in addition to its proper work, made to do duty alternately as a refinery and reheating fire, an arrangement that must be attended with considerable waste both of time and fuel. The loss upon the pig iron is from 20 to 30 per cent., including the reheating; the consumption of charcoal is from 40 to 50 cubic feet per cwt. About 75 per cent. of the produce is good steel, which is reheated in special small fires, and drawn under light hammers into bars, which are packed in cases and sold as Brescian steel.

The so-called true Brescian process practised at Paal, in Styria, differs in certain details of manipulation from the preceding, the most important point being, that in reheating the blooms, they are plunged into the bath of molten pig iron, whereby they undergo a kind of surface hardening by cementation.

In Siegen, where spiegeleisen is, or was, formerly treated in the open fire, the charge is melted down in small quantities of 60 or 80 lbs. weight upon a bottom of mottled iron. As soon as fusion commences the slag is tapped to within 2½ inches of the bottom, and further additions of spiegeleisen are made in diminishing quantities, from 40 lbs. at the fifth to 20 lbs. at the seventh and last charge. It is sought as much as possible to keep the mass at the consistency of soft butter during the entire operation. The bloom (*schrei*) ultimately obtained weighs 4 cwt., the time required being about eight hours. It is divided into seven or eight pieces, which are tilted into bars, with a loss of about 20 per cent. Reckoned upon the pig iron, the loss is 30 per cent., 100 lbs. giving 70 lbs. of steel, of which about three-fourths are of good quality, and capable of being properly hardened, and the remainder mild steel or steely iron. It is doubtful whether this process is still practised, having latterly been superseded by the method of steel puddling.

Puddled Steel. There is no essential difference between the methods of making wrought iron and steel in the puddling furnace, other than the degree of decarburisation to which the pig iron is subjected. The most highly-carburised varieties of pig iron, especially those containing manganese, such as spiegeleisen, are best adapted for the process. The furnace is usually of a somewhat smaller size than that employed for making malleable iron; or rather, the size of the bed is diminished in proportion to that of the fireplace and stack, in order to be able to command a very high temperature. The charge does not usually exceed 3 or 3½ cwt., which is introduced in fragments as nearly as possible of the same size and thickness, and spread out so as to expose a large surface to the flame, in order that fusion may be effected uniformly and without much oxidation. The use of only one kind or class of pig iron is also necessary, otherwise, supposing white and grey iron to be mixed, a portion of the charge would probably fine and come to nature while the more fusible part was still unchanged. This is exactly the reverse condition to that required in puddling for malleable iron, where a mixture of two different kinds of pigs has an advantageous effect in accelerating the process. In steel puddling, on the other hand, the charge is rendered perfectly fluid, and covered with molten slag, in order that the fining may go on slowly and uniformly. The presence of protoxide of manganese in the slag is important, as contributing fluidity without increasing the decarburising influence. By keeping the contents of the furnace well stirred together during the second part of the process, the iron separated in the malleable condition may, in the event of its becoming too much decarburised, be brought back to the proper condition by dissolving it in the unaltered pig iron below, in a somewhat similar manner to that practised in the Siegen open-fire process, where the iron is prevented from drying to too stiff a consistency by the addition of fresh quantities of pig iron at intervals. In order to induce fining in the molten mass, the damper must be closed until the charge thickens and commences to rise, when the heat must be carefully raised during the time of stirring, which usually takes from thirty-five to forty-five minutes, or somewhat longer than is the case in puddling for malleable iron. The high temperature prevailing in the furnace keeps the contents of the hearth well melted, and by continued stirring, fresh particles of metal are constantly brought to the surface of the fluid covering of slag. The appearance of fine, white, brilliant grains is a sign of the process going on well, and indicates the formation of steel of good quality and uniform texture. If, on the other hand, the separated grains are large, and resemble snow-flakes, the product is likely to be of a coarse fracture, and imperfectly refined. The slag must be less basic than that formed in puddling for malleable iron, as the presence of a large excess of oxides of iron not only reduces the fluidity, but acts too energetically on the removal of the combined carbon from the pig iron.

The balling of the granular clots of steel as they come to nature is an operation requiring considerable skill; it must be done in a neutral or non-oxidising atmosphere, such as is obtained by shutting the damper, and keeping the hearth filled with flame and smoke with an ordinary furnace, or shutting off the top blast when a gas furnace is used. The balls are shingled at a lower temperature than those of malleable iron, and when they cannot be immediately taken to the hammer, are protected against oxidation by rolling them in the melted slag, so as to obtain a superficial crust or varnish, which excludes the air from contact with the heated metal.

The slowness of the fining process, and the extra amount of stirring required, are sufficient to explain the apparent anomaly that a partial should require longer time than a complete decarburisation. Under ordinary circumstances the time required for working off a heat is in either case as follows :—

	Fibrous Iron.	Steel.
Melting down . .	30 to 40 minutes	40 to 50 minutes.
Stirring	30 ,, 35 ,,	45 ,, 50 ,,
Boiling and fining .	25 ,, 30 ,,	20 ,, 25 ,,
Balling	10 ,,	10 ,,
	85 115	105 135

As originally described in the specification of Riepe, by whom the process was introduced into England, the charge recommended to be used is 280 lbs., which is to be exposed to a red heat until the metal begins to fuse, furnace commences, it is raked into the hearth, and the whole mass is well mixed together. When the grains of steel begin to break through the cinder, as already described, the damper is to be partially closed, and the operation of stirring below the cinder commenced, taking care that the heat be not raised above cherry redness, or the welding temperature of shear steel. The remainder of the process of balling is done with a closed damper, as already described.

It appears to be doubtful, according to the statements of most of the recent writers on the subject, whether the process can be properly conducted at the low temperature specified. The use of the highest heat attainable in the puddling furnace was afterwards claimed by another patentee, and on subsequent litigation, the term "cherry redness" was explained as meaning a bright red heat when the furnace was illuminated by direct sunlight. Parry states that if the heat be too high during the boiling, the mixed cinder and metal separate from each other, and the decarburisation proceeds slowly; while, on the other hand, if the temperature be too low, the cinder and metal cannot be properly mixed, being of too stiff a consistency, and the steel will not be homogeneous. The temperature must be raised to a full yellow heat on the appearance of the floating granules in the slag. The fire should be made up at the end of the boiling process, in order to prevent the passage of air by opening the fire-hole during the balling.

It is necessary to shingle the balls as soon as possible, in order to prevent the decarburising action of the rich slag retained by capillary attraction upon the spongy particles of steel. When the slag is poor in protoxide of iron it sets very quickly, and when more basic, acts powerfully in removing carbon. The presence of oxide of manganese is advantageous, as communicating fluidity without increasing the oxidising effect—a point of considerable importance, as the shingling takes place at a lower temperature than is the case with malleable iron. In some cases an addition of peroxide of manganese is made immediately before balling, or the mixture of peroxide of manganese, clay, and salt, already mentioned as recommended by Schafhaütl for improving ordinary iron, is added at intervals after the melting down of the pig iron during the stirring.

At Lohe, in Siegen, twelve heats of 3½ cwt. of white fibrous "steel" pig iron are puddled in the turn of twelve hours. Each charge yields from seven to eight balls, weighing 40 lbs. each. The loss upon the pig iron is 9 per cent. in puddling, with a further amount of 11 per cent. upon the reheating, which is done in covered hearths with a single twyer, somewhat like the South Wales hollow fire. The blooms are drawn into bars under a tilt hammer. The produce is assorted according to the fracture: 78 per cent. is good hard steel, capable of being broken when cooled in water; the remaining 22 per cent. is more or less mixed with soft iron. The total expenditure of coal is double the weight of the steel produced: out of this 84 per cent. goes for puddling, and the remaining 16 per cent. for reheating. These quantities refer to Ruhr coal, which is not of a very high quality. The total production for twelve hours is about 34 cwt.

When grey pig iron is used, either alone or mixed with mottled, it is necessary to add from 10 to 15 per cent. of scale and cinder. In such cases the consumption of coal may be somewhat increased, as the process lasts a little longer than when working with iron smelted from spathic ores. In Styrian works using lignite, with the advantage of good pig iron, the consumption is from 32 to 42 cwt. per ton of steel blooms made, without counting charcoal and wood for reheating.

The use of gas furnaces is said to be of great advantage in the steel-puddling process, both as regards saving of fuel and diminishing the waste of iron. At Kirchhunden, in Siegen, the saving is stated at from 35 to 40 per cent. in the coal, and from 9 to 10 per cent. on the amount of iron burnt. According to observations made in several localities, the consumption of fuel is diminished when the sides of the hearth are cooled by a circulation of air instead of water.

The chemical changes going on in the process of steel puddling have been investigated by Schilling and other chemists in a similar manner to that followed originally by Calvert and Johnson. The following are Schilling's results of the composition of the metal and slag at different points of the process, as carried out at Zorge, in Hanover. The charge consisted of white pig iron from Gittelde, and grey from Zorge, mixed in equal weights. The fuel employed in the blast furnace was charcoal, the consumption being at the rate of 100 lbs. for every 87 lbs of pig iron produced:—

ANALYSES OF IRON AND SLAG TAKEN AT DIFFERENT STAGES OF PUDDLING (SCHILLING).

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Graphitic carbon .	0·08	2·13	1·11	—	—	—		—	—	—
Combined carbon .	2·60	1·03	1·81	2·49	2·36	2·26	1·77	1·33	1·08	0·94
Sulphur . . .	0·09	0·109	0·10	0·03	0·027	0·12	trace throughout.			
Phosphorus . .	0·48	0·46	0·47	0·24	0·17	0·11	0·08	0·071	0·075	0·075
Silicon . . .	0 99	1·50	1·24	0·34	0·16	0·11	0·11	0·11	0·11	0·11
Manganese . .	2·01	1·13	1·66	0·47	0·47	0·47	0·31	0·31	0·27	0·27

No. I. White pig iron from Gittelde.
" II. Grey pig iron from Zorge.
" III. Mean composition of charge.
" IV. Charges after melting down 47¼ minutes from the commencement of process.
" V. Metal at the commencement of rising, 18½ minutes from the preceding.
" VI. " during boiling 14 minutes later than No. V.
" VII. Another sample taken during boiling, 17 minutes later than No. VI.
" VIII. Granules of steel commencing to separate, 14¾ minutes later.
" IX. Sample taken at the formation of the first ball, 9 minutes later.
" X. " " last ball, "

The metal of the sample No. III. was tough and strong cast iron; No. IV., taken after five tools had been heated in rabbling, was stronger than the preceding, but of a tin-white colour; No. V. was very cellular, and resembled white pig iron, but was slightly malleable; No. VI. was decidedly malleable, and apparently possessed most of the properties of steel, notwithstanding the large amount of carbon present. No increase of carbon was observed in the earlier stages of the process, as recorded by Calvert and Johnson, and Lan. Schilling ascribes this difference to the use of a gas furnace, and the introduction of an excess of air into the furnace by the top blast:—

CORRESPONDING COMPOSITION OF SLAGS.

SLAGS TAKEN WITH	IV.	V.	VI.	VII.	VIII.	IX.	X.
Silica . .	20·98	20·51	20·12	20·34	20·27	20·40	20·52
Phosphoric acid	5·25	5·25	5·25	5·25	5·25	5·25	5·25
Peroxide of iron	7·12	4·09	4·12	5·20	5·20	4·95	6·24
Protoxide of iron	58·98	62·03	62·14	61·20	61·20	61·34	59·88
Alumina . .	2·78	2·82	2·87	2·87	2·91	3·05	2·86
Protoxide of manganese	1·64	1·64	1·64	1·64	1·64	1 64	1·64
Lime . .	1·84	2·14	2·04	1·69	2·12	1·72	1·69
Magnesia . .	1·62	1·51	1·63	1·52	2·04	1·81	1·79
Alkalies . .	0·93	0.82	assumed at 0·87				
Sulphuric acid	trace		not determined				
	101·14	100·81	100·68	100·58	101·50	101·03	100·74

In these slags, which are nearly uniform in composition throughout, the oxygen ratio of acid to bases is as 11·687 : 18·212, or nearly 1 : 1½ that of a sesquibasic silicate. This is supposing the peroxide of iron to be in combination with silica, and not replacing it. The large and constant amount of phosphoric acid is ascribed, not to the oxidation of phosphorus contained in the pig iron, which is obviously in too small a quantity to produce such an effect, but to the ash of the wood burnt in the gas generator, and carried over by the draught, owing to the defective arrangement of the ash pit. It is evident, therefore, that even the above elaborate series of analyses does not furnish us with an exact idea of the changes going on during the process.

Production of Steel by Cementation. This process consists essentially in the exposure of bars of malleable iron, in close contact with charcoal, to a high and long-continued heat, the air being excluded. The furnace, Fig. 41, employed for this purpose, is an oblong chamber with a semi-cylindrical roof, containing two large chests or converting pots, *a a*, also of rectangular form, which are heated by a fire grate, *c*, placed below them, and running along the entire length of the chamber. The flame is distributed uniformly by a system of transverse rectangular flues, *d d*, across the bottom and up the sides of the pots, and finally passes through a number of short vertical chimneys in the sides of the chamber into a tall covering hood or stack, *e*, of conical form, like that of an ordinary glasshouse furnace or potter's kiln. The size of the boxes varies in different localities, according to the weight of iron heated at one time, from 8 to 15 feet in length, and from 2½ to 3 feet in breadth and height, corresponding to a capacity of between 8 and 12 tons of bar iron, with the necessary quantity of cementing powder. In Yorkshire they are usually built of sandstone flags, but in other places ordinary fire-bricks and lumps or slabs of the same material are used. The introduction and withdrawal of the charge are effected through man-holes, *b*, in the shorter side walls of the covering chambers, placed above the level of the top of the boxes: these holes are of course walled up with brickwork when the furnace is lighted. In some instances, where the furnace is of small size, the roof of made in several pieces, so as to

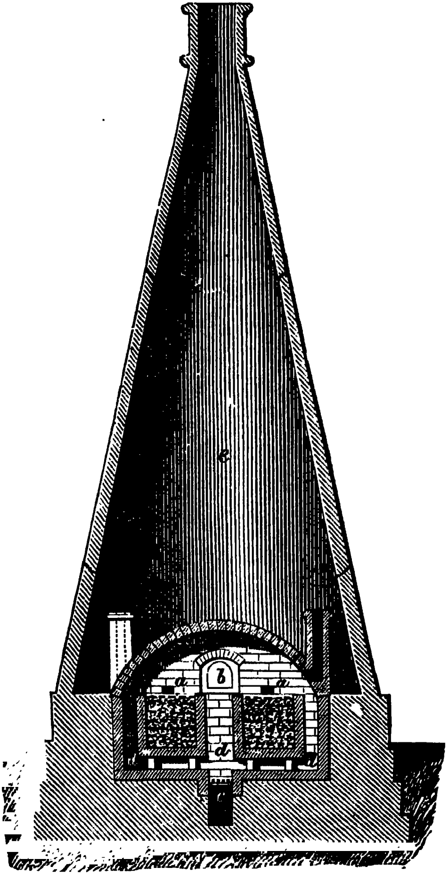


Fig. 41.—Steel-converting furnace.

be easily removed at the end of the operation, in order to facilitate the withdrawal of the cemented bars. Two small square holes, communicating with the interior of the boxes, are placed a little lower down on the same side of the furnace; these contain the trial bars used in determining the progress of the conversion.

Bar iron smelted from Swedish magnetic ores is used in the production of the best kinds of cement steel at Sheffield, and, as a rule, hammered bars are preferred to those made by rolling. The most esteemed brands are those produced at the small forges in the eastern part of Sweden, in connection with the Dannemora mines; that of Löfsta, known as Ⓛ iron, having the highest reputation. The ordinary sizes of bars employed are from 2 to 5 inches in breadth, and from one-third to three-quarters of an inch in thickness; a flat form being preferred to those of round or square section. In filling the pots, an allowance is made for the expansion of the iron by heat; a space of about 2 inches in the direction of the length, and a little less transversely, being left between the edges of each layer of bars and the walls, and in like manner the butt ends of adjacent bars in each line must not be brought in contact with one another.

The cementing material is in all cases charcoal, in the form of a coarse powder obtained by sifting through a riddle with ½ or ¾-inch meshes. No special variety of charcoal is necessary, that of the hardest wood obtainable in the neighbourhood being generally used; as, for example, birch in Sweden, beech in Rhenish Prussia, and oak in England. Hard-wood charcoal is said to be advantageous on account of the large amount of alkaline salts in the ash, which are regarded as favouring the production of cyanogen compounds. For the same purpose, an addition to the charcoal of small quantities of carbonate of baryta, alkaline carbonates, yellow prussiate of potash, animal charcoal, or organic matter containing nitrogen, has been recommended at different times, and tried experimentally; but none of these substances are in general use, except in the superficial converting process of case-hardening.

In charging the pots, the bottom is first covered with a coating of charcoal, and upon it the bars are arranged in tiers lying on the flat sides, and separated from each other by a layer of charcoal about half an inch thick. About one-third of the total cubic contents of the pot is occupied by the iron, the remaining two-thirds being filled with charcoal. When the whole charge has been introduced, the top of the pot is covered with a layer of clay or other refractory material. At Sheffield, grinder's waste, or wheelswarf—a mixture of finely-divided, partially-rusted steel with quartzose sand, produced by the waste of the grindstones employed in grinding cutlery—is generally used. It is plastered over in a damp state, and frits together to a kind of glaze when strongly heated, forming a covering impervious to the air. A certain proportion of fresh charcoal, to the extent of one-half or two-thirds of the total quantity, must be used in each operation; that remaining from a former charge requires to be subjected to washing and sifting before it can be used again. The mixture of the two kinds is found to give a better result than when fresh coal is used alone, and the conversion is more rapidly effected.

When the furnace is charged, all the apertures are carefully stopped with brickwork or fire-clay, to prevent the access of air. The fire is then lighted, and in about twenty-four hours the chests are raised to a red heat, and in about two or three days more will have attained the proper temperature. According to the nature of the steel required, the fire is kept up for a period of from seven to nine or eleven days; the hardest quality for melting purposes requiring the longest, and spring and shear steel the shorter time. Conversion begins at a temperature of about 1,000°, but goes on more actively at the melting point of copper, about 1,170°: at higher temperatures cast iron is produced.

The progress of the conversion is determined by the appearance of the trial bar; the first is taken out after about a week's firing. When there is no longer an unaltered kernel of soft iron apparent in the centre, the conversion is considered to be complete, the fire is allowed to go down, and the furnace is left to cool for three days; the man-hole stoppings are then removed, and on the sixth day the withdrawal of the cemented bars is commenced, and takes one or two days more, so that the whole operation requires from seventeen to twenty days. The physical properties of the iron are considerably modified by conversion; the colour of the fractured surface changes from the original bluish tinge of malleable iron to a somewhat reddish white, like that of bismuth, and at the same time the lustre is considerably diminished. The texture is in all cases scaly crystalline. The finer the grain and the darker the colour, as a general rule, the more highly carburised or harder will be the steel produced; at the same time, both specific gravity and tenacity are reduced. A more decided peculiarity of the converted bars, however, is the blistering of the external surfaces, whence the term *blister steel* is derived. When the blisters are small, and tolerably regularly distributed, the steel is of good quality; but when large, and only occurring along particular lines, they may be considered as indicative of defective composition or want of homogeneity in the iron employed. The cause of this phenomenon is not quite clearly made out. The most probable explanation is, that it is due to the irregular action of the cementing material upon included particles of slag, consisting of basic protosilicate of iron, which is reduced to the metallic state with the evolution of carbonic oxide, which blows up the surface of the metal when in a softened condition from the heat of the furnace. The average increase of weight in the conversion of bar iron into blistered steel is from ½ to ¾ per cent. The fuel necessary per 100 lbs. of the latter is as follows:—

Coal	75 to 90 lbs.
Lignite	160 „ 210 „
Peat	200 „ 300 „
Wood	300

Blister-steel bars may be used for common purposes, such as steeling the faces of hammers, without further treatment; but more generally they are subjected to one or more reheatings in packets or faggots, and weldings by hammering or rolling, whereby the texture becomes more uniform, and strength and elasticity are increased, but with a progressive diminution of hardness. Spring steel is produced by heating blistered bars at an orange-red heat, and drawing them down either under the hammer or by rolling. *Shear steel* is a better quality, obtained by drawing the original bars to lengths of 3 feet, which are piled together in faggots and welded, the reheating being effected in a hollow fire. The surface of the faggot is covered with clay, which forms a cinder in the heating process, and prevents the blast from acting on the combined carbon of the crude bars. The product of this operation is known as *single shear*. It may be further refined by doubling the bars, and repeating the process of heating and welding, making double-shear steel. The best and most uniform quality of steel can, however, only be obtained by fusing the blistered bars in crucibles—a process that will be noticed further in page 354.

Case-hardening, or the production of a thin superficial layer of steel upon malleable iron, is a rapid process of cementation carried out on a small scale. An iron box, heated in a smith's forge, is used as a cementation chest. The charcoal is usually obtained by carbonising animal matter, such as bones, horn, or leather. The articles to be case-hardened are embedded in the charcoal in the ordinary way, and are then exposed to heat for a short time, taking care not to use too high a temperature. Under the most favourable circumstances the cemented layer may attain a depth of about three-eighths of an inch in four or five hours. The work, when removed from the fire, is hardened by plunging it while in a heated state into cold water, if it is required to be uniformly hard over the whole surface, otherwise it is allowed to cool, and the steeled surface is removed by turning down such parts as are intended to remain malleable, and the other portion is subsequently hardened by heating and quenching in water as before.

The following is the most rapid method of case-hardening:—The piece of iron to be treated, after being polished, is raised to a bright red heat, and the surface to be hardened is rubbed or sprinkled with finely-powdered yellow prussiate (ferrocyanide of potassium). As soon as the powder has volatilised or disappeared, the work is quenched in cold water in the usual way. If the process has been properly conducted, the surfaces covered by the salt will be found to have become hard enough to resist the file.

Malleable Cast Iron. The process of annealing, or rendering the surface of cast-iron articles malleable, so that they may be filed or hammered, is a kind of inverse cementation, finely-divided peroxide of iron being employed to remove the carbon from the surface of the casting. Cast iron smelted from red hematite is generally preferred for this purpose, especially that made with charcoal. The fusion takes place in crucibles in an ordinary air furnace, such as is used for smelting cast steel, coke being employed as fuel. The castings, when removed from the moulds, are very brittle, and cannot be touched with the file. They are then packed in cast-iron crucibles containing powdered red hematite, which are arranged in rows one above another in a furnace of rectangular section, somewhat similar in character to an ordinary cementation chamber. When the furnace is charged, all the apertures are carefully closed, and heat is applied gradually, so that the whole contents may be brought up to a red heat in twenty-four hours; the firing is then continued for from three to five days more, according to the depth of the malleable skin required on the finished work. Articles of irregular thickness that are intended to be bored out must be subjected to the process a second time, in order to obtain the proper degree of alteration.

The appearance of the finished articles, when drawn from the furnace, is similar to that of malleable iron, but lighter in colour; the density is about the same as cast iron, the increased specific gravity of the malleable portion being counteracted by its porosity. The fractured surface is white and finely granular, with a very high lustre, occasionally presenting a grey silky appearance, recalling that of soft steel. When the thickness of the object is more than half or two-thirds of an inch, a kernel of very soft grey cast iron is left in the centre. In the latter case the central portion may sometimes be broken by bending the object without the external skin giving way.

Malleable castings, prepared in the above manner, may be easily wrought cold, but become very brittle when heated, breaking to pieces under the hammer at an incipient white heat; at a higher temperature the kernel of unaltered cast iron melts, so that articles that have been subjected to the process cannot be united by welding, but may be brazed without difficulty. On account of the more refractory nature of the material, the use of malleable cast-iron crucibles has been suggested for melting silver in mints, instead of the cast-iron pots ordinarily used for that purpose.

The principal application of the process is, however, to small articles of hardware, such as keys, buckles, gun furniture, &c. Recently, however, it has been applied on a larger scale by M'Haffie, of Glasgow, to parts of machinery, such as toothed wheels and screw propellers, the latter having been successfully adopted in steamers employed in the whaling and sealing trade in the Greenland seas, where ordinary cast-iron screws are especially liable to be broken by the floating ice.

The malleable skin may be partially converted into steel by case-hardening in the same way as ordinary soft iron, so that these different states of cast iron, malleable iron, and steel may be combined in the same object. Common articles of cutlery made in this way are distinguished as *run-steel* goods.

Production of Steel by Fusion. In all the preceding methods, the steel produced, whether by fining or cementation, is, as a rule, very unequal in quality ; and uniformity can only be attained by repeated faggoting and welding, steps which are necessarily attended with a loss of carbon, and consequent reduction of hardness. The requisite uniformity of composition may, however, be obtained by breaking up the crude bars produced in the forge, or by cementation, and exposing them to a strong heat in crucibles out of contact with the air. The product, when melted, is poured out into cast-iron moulds, forming ingots of *cast steel,* which are much more regular in composition and texture than the original material.

The practice of melting steel was introduced at Sheffield by Huntsman about the year 1740, and is still carried out in substantially the same manner at the present day. Although a simple operation, it is an expensive process, owing to the large consumption of fuel and crucibles required for a comparatively small production of ingots.

The general arrangements of a steel-melting house are shown in the transverse section, Fig. 42.

The furnace, or *melting hole, a,* is a small square or oblong chamber, about 3 feet deep, from 1½ to 2 feet square, lined with refractory materials, such as firebrick or the siliceous stone known as ganister. The top of the furnace is placed level with the floor of the casting house, the grate bars and ash-pit being accessible through a vaulted cellar, *b,* below. The cover of the furnace is a square or quarry of fire-brick set in an iron frame with a projecting handle. There is a short lateral flue near the top of the furnace, communicating with the stack, which is nearly of the same sectional area as the furnace, and about 40 feet high, in order to command a strong draught. Several furnaces are usually arranged in longitudinal series on opposite sides of the casting house, leaving the centre of the floor clear for placing the moulds.

The crucibles used are made of mixtures of different kinds of fire-clay from the coal measures, with a certain proportion of ground potsherds and coke dust; the usual size is from 16 to 18 inches in height, and from 5 to 7 inches in diameter at the mouth, with a slight belly at about two-thirds of the height from the bottom.

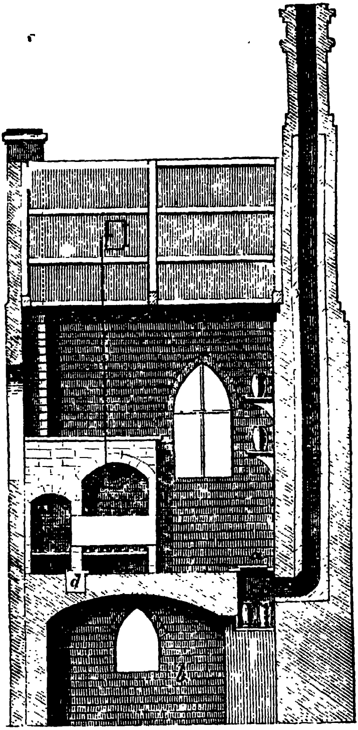


Fig. 42.—Cast-steel melting furnace.

The capacity varies from 35 to 80 lbs. Usually two pots are placed in a furnace: they stand upon cylindrical discs or cheeses of fire-brick resting on the grate bars. Previously to being used they require to be gradually heated to redness in an open fire or annealing grate, *c*, which is done by placing them in batches of twenty, bottom upwards, together with their covers, upon a bed of red-hot coal in the grate; and the intermediate space is then filled with coke, and the fire is urged until the necessary heat has been obtained. The pots are then removed to the melting furnaces, and fixed in position on their stands. The fires are replenished with coke, and as soon as they have been brought up to a strong heat, which takes place in about twenty minutes, the charge of blister steel, properly assorted and broken into small pieces, is introduced through a wrought-iron funnel; after which the cover is placed on the top of the pot, and the full heat of the furnace is given for about three and a half hours, during which time fresh fuel must be added every three-quarters of an hour. When the fusion is complete, which is ascertained by removing the cover and searching the contents of the crucible with a pointed rod, in order to ascertain whether any hard unmelted lumps remain, the crucible is cleared from adherent slaggy masses by stirring below the grate, and is then lifted out by the furnaceman with a pair of curved-nosed tongs. The ingot mould, made of cast iron, is blackened by coating it with train oil and heating; or, in some cases, a thin wash of fire-clay, mixed with water to the consistency of cream, is used. When the pot is removed from the furnace it is deposited in the teaming hole, *d*, a small pit filled with broken pieces of coke, and the lifting bags are changed for those used in casting. The contents of the crucible are allowed to cool for a short time before pouring. When the ingot mould is filled, its mouth is covered with a plug of cast or wrought iron, or a shovelful of sand, in order to prevent the top of the ingot from becoming spongy by the escape of gases before solidification.

After the first cast the crucible is cleared from adherent clinker, and returned to the furnace for a second melting. The charge is somewhat reduced, and the consumption of coke, as well as the time of fusion, is diminished in a similar proportion. Thus the first melting takes from four to six hours, while the second and third only require from two to two and a half hours each. The furnace is allowed to cool after from three to five meltings have been made, as there is no advantage to be gained by keeping it constantly heated, owing to the corrosion of the lining bricks produced by the very high temperature, whereby the capacity and power of consuming fuel is increased, without a corresponding increase in the amount of steel melted.

Under ordinary circumstances, the total amount of coke burnt is from three to three and a half times the weight of the ingots produced, when of a good quality; but when made from inferior varieties of coal, it may be as high as five or six times the weight.

In France furnaces are used capable of containing a large number of crucibles which are not brought into direct contact with the fuel, but are arranged in series in a chamber, which is heated by a fireplace similar to that of a reverberatory furnace. The chambers, which are made to hold from four to nine pots, are covered with a square lid in the usual way. In addition to the chimney draught, a blast is used below the grate, and a portion of the waste heat is sometimes applied to raising steam for the hammers and rolling mills used in finishing the ingots. Siemens' regenerative gas furnace has also been applied with considerable advantage to steel melting, and by its use the consumption of fuel per ton is reduced from 3½ tons of coke to 1½ tons of inferior slack. The arrangement, which is somewhat similar to that of the regenerative puddling furnace already noticed, is shown in Fig. 43, where the pots, placed in four series of eight each in the chamber, are heated by the combustion of gas and air, which have been previously raised to a very high temperature by

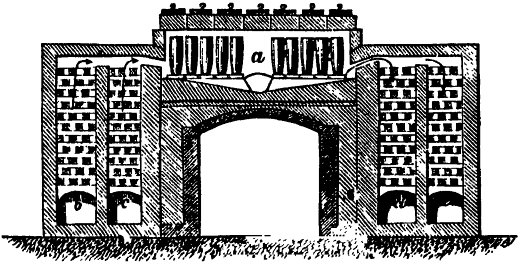


Fig. 43.—Siemens' cast-steel furnace. Section through melting chamber and regenerators.

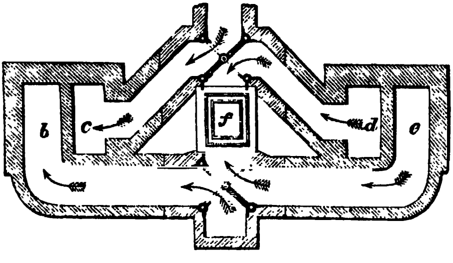


Fig. 44.—Siemens' cast-steel furnace. Plan of flues.

their passage through the left-hand pair of regenerators, *b c*, the excess of heat carried out of the melting chamber being absorbed by the brickwork in the right-hand pair, *d e*. When the latter have become heated as the former cools, the current is reversed by turning the valves, admitting the air and gas into the position shown by the dotted lines in the section, Fig. 44. The course of the two currents is shown by the arrows. The spent gases, after giving up their surplus heat, escape by the chimney at *f*.

When very large masses of cast steel are required, the contents of all the crucibles are either poured into a foundry ladle before filling the mould, or the pouring is so arranged that by bringing up relays of fresh pots, a constant stream may be kept up without intermission. In this way large castings, up to as much as 40 tons, are made by Krupp, in Essen, from crucibles containing 70 lbs. of steel. The furnaces hold from 2 to 24 pots each. The materials used are reported to be puddled steel and wrought-iron scrap, with an addition of carbonaceous matter, in order to render the malleable iron fusible, a somewhat similar process to that adopted in making the native Indian steel called wootz.

The drawing of the crucibles from the furnace is also facilitated by placing them on a platform, which is raised by a mechanical lifting apparatus placed below the ash-pit, thus doing away with the use of lifting tongs.

At the River Don Steel Works, in Sheffeld, cast steel is largely made by the method introduced by Mushet in 1801, which consists in melting malleable scrap iron with charcoal and oxide of manganese in crucibles directly, without using any blister steel. The furnaces are 288 in number, each of sufficient size to contain two pots charged with 100 lbs. With the whole number at work, a casting of 25 tons' weight may be made, the pouring from the 576 pots being completed in five minutes. In order to keep up the supply, the pots are conveyed from their melting holes to the casting place on small barrows, instead of being carried by the tongs, as was formerly the custom. The steel produced is to a great extent employed in making castings for direct use, such as railway crossings, wheels, and bells, instead of merely running it into ingots, which are subsequently worked up under the hammer. The moulds used for this purpose are made sufficiently refractory by the use of a thin layer of burnt clay, produced by grinding old melting pots, which is applied immediately over the pattern, the remainder of the box being filled with ordinary moulding sand. This method of steel casting was first practised at Bochum, in Westphalia, where it is still carried out on a very large scale. Castings made to pattern, which are not intended to be subsequently hammered, must be annealed and allowed to cool very slowly.

An addition of manganese, either as a carburet reduced by heating the oxide with carbon at a very high temperature, or a mixture of black oxide of manganese with carbonised pitch or resin, is very commonly used for improving steel in the process of melting. This is the celebrated process of Heath, which formed the subject of long and protracted litigation a few years back.

The appearance of the fracture surfaces of ingots of cast steel varies with their hardness or relative proportion of carbon. The softer kinds are bright and finely granular. The harder qualities often show crystalline plates of a certain size, arranged in parallel stripes or columns at right angles to the surface of the mould, so that in a square ingot the columns intersect, forming a cross. In all cases the ingots are more or less unsound, being filled with small vesicular cavities, so that they require to be reheated and hammered before they can be converted into bars. This is done in the manner already described for making shear steel, care being taken to effect the reheating at as low a temperature as possible, and to prevent the metal from burning by keeping it out of access of the air while in the fire.

Bessemer's Process. This, one of the simplest methods of producing cast steel in large quantities, combines the action of the puddling and ordinary steel-melting furnace into one operation. The essence of the process consists in injecting large quantities of air into a bath of molten cast iron through a large number of small orifices, in order that the combustion of the carbon and other matters in combination may take place rapidly and uniformly. By this means a very high temperature is developed in the converting vessel, the heat being sufficient to melt the decarburised malleable iron, instead of producing it in a pasty, weldable condition, as is the case in the puddling furnace. This great increase of temperature is obviously due to the rapidity of combustion, owing to the intimate contact of the air, which is injected at a much higher pressure, from 15 to 20 lbs. to the square inch, than is used in the ordinary operation of iron-melting, with the molten metal, instead of the decarburised iron merely taking place at the surface of the bath, or where the pasty metal is in contact with particles of scale, cinder, or similar oxidising agents, as is the case in puddling. It will be remembered that, in the latter process, the temperature of the puddling furnace has to be artificially reduced by closing the damper, in order to bring about the reactions between the different portions of the charge, which only go on very slowly when the contents of the hearth are in a liquid state. In Bessemer's process, however, the increase of temperature goes on progressively from the moment the blowing commences until the conclusion of the operation, the heat produced being developed by combustion going on in the molten mass, in the order in which the combined foreign substances are removed being similar to that observed in puddling and refining. After the whole of the carbon has been eliminated, the heat is kept up, if the blowing be prolonged by the combustion of the iron, giving a product exactly similar in general properties to the *burnt iron* which is obtained when malleable iron is too often or too highly heated in the process of welding.

This process is, therefore, not adapted for the production of soft malleable iron, but, with certain modifications, is capable of producing steel of good quality, within a considerable range of composition and hardness. This may be done in two ways: the first is that practised in Sweden, where the blowing is interrupted after partial decarburisation of the charge, the proper moment for stopping the operation being determined by the appearance of the flame issuing from the mouth of the converting vessel; or the metal may be completely decarburised, and then brought back to the composition of steel by the addition of highly-carburised melted pig iron, such as spiegeleisen, in sufficient quantity to restore the necessary amount of carbon. The latter modification of the process is due to Mushet, and is now generally preferred to the older method, as being more certain in result.

The varieties of cast iron best adapted for conversion into steel by the Bessemer process are those smelted from hematite or magnetic ores not below No. 2 in greyness. White iron can only be treated with difficulty and increased waste, partly owing to its imperfect fluidity when melted, which increases the resistance offered to the passage of the blast, but more particularly on account of its deficiency in carbon and silicon. The carbon being in the combined state, the production of carbonic oxide takes place at too early a stage of the process, and not being present in sufficient quantity, prevents the attainment of the proper temperature in the converting vessel.

The chief essentials in the chemical composition of the pig iron are, almost absolute freedom from sulphur, phosphorus, and copper, as neither of these ingredients is sensibly reduced in amount by the process; silicon and manganese, on the other hand, may be almost completely removed, and their presence is beneficial within certain limits. As long as manganese remains scarcely any iron is oxidised, the silica produced from the silicon of the metal uniting with protoxide of manganese to form a slag, which is very fluid, but also is very destructive to the siliceous linings of the converting vessels.

The best English pig iron for use in the Bessemer process is that smelted from Cumberland hematite, about No. 1 or No. 2 in greyness. It should contain from 1½ to 2 per cent. of silicon as a minimum, and not more than 0·2 per cent. of phosphorus. At Essen, in Westphalia, the limiting quantities of foreign matters in the pig iron preferred for Bessemer steel-making are as follows, according to Jordan. The metal generally used is smelted from mixtures of spathic ore and Nassau hematite.

Manganese,	maximum	1·00	per cent.
Sulphur	„	·04	„
Phosphorus	„	·06	„
Carbon	minimum	5·00	„
Silicon	„	2·00	„

The furnaces, or *converters*, employed in the process are of two different kinds. The oldest, or fixed form, which is still in use to a certain extent in Sweden, is a cylindrical vessel of refractory brickwork, somewhat similar to a foundry cupola, but broader and lower in proportion. Near the bottom, which is made with a slightly forward incline towards the tap hole, is placed a series of small twyers, which are arranged at equal distances around the entire circumference. The top of the vessel is covered by a dome, terminating in a conical neck, turned towards a hood placed above it, for carrying off the flame and sparks given out during the blowing.

The second, or movable, form of converter, which is now almost universally adopted, consists of an egg- or pear-shaped vessel suspended upon trunnions, and provided with appropriate moving mechanism, whereby it may be rotated vertically through an angle of about 180°. The outer casing or shell is made of wrought-iron plates riveted together, and, as originally made, was not unlike a soda-water bottle in shape, supposing the pointed end to be flattened, and the neck turned over at an angle of about 30° to the body. In the newer forms, however, especially those intended for working with large charges, increased capacity is obtained by making the body and lower part cylindrical, thus approximating in outline to the older fixed converters, as in Fig. 45.

The suspension is effected by means of a stout hoop of wrought iron or steel carrying two trunnions, which is shrunk on to the body of the converter at the widest part. One of these trunnions, which run in bearings supported by cast-iron standards, is solid, while the other is hollow, forming a passage for the blast, and carries a spur pinion.

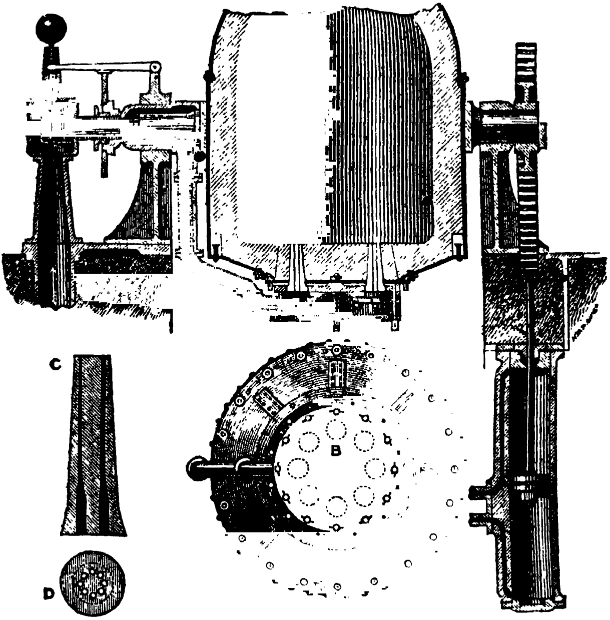


Fig. 45.—Bessemer's steel converter.
A. Transverse section through trunnions.
B. Bottom plan.
C. Section of twyer brick. D. Plan of ditto.

The interior lining of the converter must be made of the most refractory material obtainable. Fire-brick or clay may be used; but in Sheffield, and in England generally, a nearly pure siliceous sandstone from below the coal measures, known as ganister, is found to be better adapted for this purpose than any other substance. It is prepared by grinding to a fine powder, and may be used alone or mixed with a certain proportion of powdered fire-brick; in either case a small quantity of water is used, sufficient to make the powder slightly coherent, which is then rammed hard between the inside of the shell and a wooden cone, which is afterwards removed. The old form of vessel is made in two parts, which are united by screw bolts, and can be taken apart for convenience in lining. In the cylindrical-bodied form, the lower part is made removable, the union being effected by eye-bolts and cotters.

The bottom of the converter is in either case flat, and contains the twyer box. This is a cylindrical chamber, connected by a curved pipe with the hollow trunnion. The twyers are cylindrical or slightly tapered fire-bricks, each perforated by seven parallel holes, about half an inch in diameter. Usually from five to seven of these bricks are used, which are arranged vertically and at equal distances apart in the lining of the bottom of the converter. Their lower ends pass through a perforated guard plate in the top of the air chamber, the vertical position being maintained by stops bearing against horizontal arms, which may be turned on one side, when it is necessary to remove or replace the bricks, without being obliged to take out the bottom of the converter.

The mechanism for turning the converter about its axis is of a simple character, consisting of a direct-acting water-pressure engine, whose piston rod carries a rack gearing into the pinion on the trunnion. At first the cylinder was placed horizontally, but in the newer form of construction a vertical position is generally preferred, as it occupies less ground space. The engine is double-acting, the valve being worked by hand gear placed at a distance.

In Bessemer steel work two converters are usually placed opposite to each other with a deep cylindrical casting pit between them. In the centre of the pit is fixed another water-pressure engine, with a vertical cylinder and solid plunger piston, carrying at its upper end a cross arm, formed of two parallel girders strongly braced together, to one end of which is attached the ladle, the overhanging weight being supported by a counterpoise attached to the opposite end. The ladle, which is similar to that used by iron founders, but considerably larger, is made of wrought iron lined with fire-clay, having a small hole in the bottom for running out the melted steel into the ingot moulds placed below. The hole is closed by an iron rod coated with fire-clay. The opposite end of the rod passes through a slide bar on the outside of the ladle, and may be raised or lowered by means of a hand lever. In order to traverse the ladle about the central pillar, so as to bring the centre of the hole over each of the moulds in succession, the top platform is provided with spur gearing, so that it may be moved like a railway turn-table. This motion is worked by a man standing on the platform, as is also another for reversing the ladle on its bearings, in order to remove the waste after the end of the cast. The valve of the central engine, which raises and lowers the ladle, is in charge of the same man who works the tipping engines for the converters. He is usually stationed in a box at one side of the converting house, raised a sufficient height above the ground to command a clear view of the whole of the apparatus. The power for working the engines is obtained from a small steam engine driving the necessary force pumps, which deliver their supply into two accumulators for equalising the pressure.

The arrangements alluded to in the preceding paragraph are represented in elevation in Fig. 46. *a a* are the two converters, each capable of holding 3 tons of molten pig iron; that on the right-hand side is lowered for filling, while the other is upright and in the position for blowing, the flame rising from the neck being carried into the chimney by the wrought-iron hood *f*. *b b* are the two hydraulic engines working the tipping gear. *c* is the central crane carrying the ladle. The cylinder, which is sunk below the level of the bottom of the casting pit, is only partly represented. The horizontal racked rod gearing into a pinion on the ladle is a slow-motion adjustment for bringing the hole through which the steel issues immediately over the centre of the mould. It is worked by a tangent screw from a handle attached to the platform carrying the ladle. The traversing motion, consisting of a small pinion gearing into a large fixed spur wheel on the central pillar is worked by a hand wheel, also on the platform, the two handles being placed close together, so as to be within reach of the workman superintending the casting. *d d* are cranes employed for removing the ingots from the casting pits. They are similar in general construction to that last described, being lifted and turned by hydraulic pressure. *e* is the box containing the valve handles of the various engines. The central hand wheel governs the vertical motion of the casting crane, while the outer ones are in connection with the tipping engines

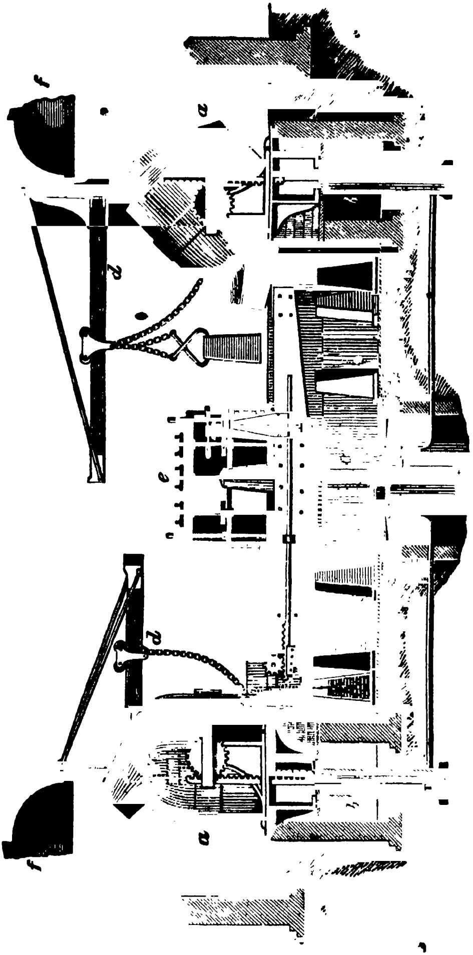


Fig. 46.—Bessemer's steel-converting apparatus.

of the converters. The levers outside work the valves of the ingot cranes.

The method of conducting the process is as follows:—The charge of pig iron, which may be of any weight between 1½ and 10 tons—3 to 5 tons are commonly used in this country, and the smaller weights on the Continent—is melted in a reverberatory furnace, or sometimes in a cupola placed in an adjoining house. The converter, having been previously brought up to a red heat by filling it with ignited coke, is reversed in order to remove any unconsumed fuel, and afterwards turned back to a horizontal position, to receive the charge of molten metal, which is run in through a movable gutter of wrought iron lined with sand. It is then slowly brought back to the vertical position, and the blast is turned on. At first the flame issuing from the neck is of a yellowish or reddish colour, but slightly luminous, with only a comparatively small amount of sparks. During this period, lasting from four to six minutes, the action going on is similar to that in the refinery in the first stage of puddling, namely, the conversion of graphitic into combined carbon, and the oxidation of silicon, with the formation of a silicate of protoxide of iron and manganese. In the second or boiling period, when the oxygen of the blast begins to attack the carbon, the action becomes very violent, the flame increases in brilliancy, and great showers of sparks, fragments of burning iron, and finely-divided slag are thrown out, owing to the rapid ebullition produced by the evolution of carbonic oxide from all parts of the melted metal. This lasts for about six or eight minutes longer, when the sparks diminish and the action goes on more quietly without the production of sparks. The flame gives the characteristic bluish violet of carbonic oxide, and is intensely hot—a point marking the last or fining stage. When the last trace of carbon is burnt away, the flame suddenly drops, and is succeeded by a stream of luminous white-hot gas, consisting principally of nitrogen, the heat being kept up from this moment, if the blowing be continued, entirely by the combustion of the molten decarburised iron. As soon, however, as the flame indicates that the whole of the carbon is removed, the converter is turned back to the horizontal position, and the proper quantity, usually about 10 per cent., of molten spiegeleisen, or other similar compound of iron, carbon, and manganese, is run in from the air furnace in the same manner as the original charge. Formerly the blowing was resumed for a few minutes after addition of the spiegeleisen, but this is now discontinued, and the contents of the converter are emptied into the ladle, which has been brought into the proper position by lowering the central pillar of the crane. The ingot moulds usually employed are made of cast iron, open at both ends, of an octagonal or circular form of base, and somewhat smaller in diameter at the top than the bottom. They are arranged in a semicircle on the floor of the casting pit. The ladle is raised to a sufficient height to clear the top of the moulds, and is turned so as to bring the hole over the centre of each one successively; the plug is lifted, and the molten steel flows out in a stream about an inch thick. Care must be taken to prevent the stream from striking against the side of the mould, in which case the ingot is likely to be unsound. When the mould is filled a small quantity of sand is thrown on the surface of the metal, which is then covered by a piece of thin sheet iron, and the whole is secured by a cross bar passing through two eyes on the top of the mould.

After the converter is charged, the blast must be admitted before it is turned back to the vertical position, otherwise the molten metal would run down through the twyers. A pressure of from 5 to 6 lbs. per square inch is required to overcome the hydraulic head of the liquid column of metal, and from 9 to 14 lbs. more to force the air through at the proper velocity, or from 15 to 20 lbs. per square inch total pressure.

An arrangement for opening and shutting the valve by the rotation of the converter is shown in Fig. 45. The valve, which is of a double-beat form, has its stem prolonged upwards, and carries a weight tending to keep it pressed against its seat. The lifting mechanism consists of a lever worked by an eccentric disc attached to the axis of the converter. When the latter is lowered for filling, the pressure of the eccentric is taken off the lever, and the valve closes ; but when the motion takes place in the opposite direction, the cam part of the disc lifts the lever, and with it the valve. By this arrangement, the opening and shutting of the valve at the right moment, a point of great importance, are made completely independent of the action of the man working the converter. The form and method of arrangement of the twyer bricks are shown in plan and section in Fig. 45, C and D.

In Sweden and Austria the process is usually conducted without remelting the pig iron, which is tapped directly from the blast furnace into the converter. In the former country the addition of spiegeleisen was formerly dispensed with, the blowing being only continued for a very short time after the more rapid boiling has ceased. The uncertainty of being able to stop the process at the right moment has led to the more general adoption of total decarburisation, and the addition of spiegeleisen in the manner already described.

Various highly-carburised compounds of iron and manganese have been introduced as substitutes for spiegeleisen in the Bessemer process. Among these are Prieger's ferro-manganese, which is made by heating mixtures of pyrolusite, charcoal, and finely-divided scrap iron in crucibles containing from 30 to 50 lbs. weight to a white heat. The alloys obtained contain from 66 to 80 per cent. of manganese. Henderson's alloy, made in Glasgow, is of a similar character, containing from 15 to 30 per cent. of manganese.

In Styria the use of spiegeleisen is entirely dispensed with, the restoration of the proper amount of carbon to the burnt iron being effected by the addition in proper quantity of a similar pig iron to that constituting the original charge.

It need scarcely be said that the reactions going on in the Bessemer converter are substantially similar to those observed in puddling and hearth fining. The following is the most complete series of analyses, taken at different stages of the process, hitherto published. It refers to the Austrian Government Works at Neuberg, in Styria. The pig iron operated upon is smelted from the spathic ores of the Erzberg with charcoal.

ANALYSES OF METAL.	I.	II.	III.	IV.	V.
Carbon, graphitic .	3·180	—	—	—	—
„ combined .	0·750	2·465	0·949	0·087	0·234
Silicon . .	1·960	0·443	0·112	0·028	0·033
Phosphorus . .	0·040	0·040	0·045	0·045	0·044
Sulphur . . .	0·018	trace	trace	trace	trace
Manganese . .	3·460	1·645	0·429	0·113	0·139
Copper . . .	0·085	0·091	0·095	0·120	0·105

No. I. Original pig iron.
„ II. Metal taken at end of first stage.
„ III. „ „ after the boil.
„ IV. „ „ end of the blowing.
„ V. „ restored to steel by addition of pig iron.

COMPOSITION OF SLAGS.	II.	III.	IV.	V.
Silica	46·78	51·75	46·75	47·27
Alumina	4·65	2·98	2·80	3·45
Protoxide of iron . .	6·78	5·50	16·86	15·43
„ manganese .	37·00	37·90	32·23	31·89
Lime	2·98	1·76	1·19	1·23
Magnesia	1·53	0·45	0·52	0·61
Potash Soda	traces throughout			
Sulphur	0·04	trace	trace	trace
Phosphorus	0·03	0·02	0·01	0·01

These analyses are numbered to correspond with those of the metal taken at the same time.

It will be seen from the above analyses that the iron is not oxidised by the blast to any great extent until nearly the whole of the manganese and carbon have been removed. The retention of the entire quantity of phosphorus contained in the original pig iron in the finished steel is in accordance with observations made in other countries. Various methods have been suggested and tried for its removal, but hitherto without success The problem of making steel from the ordinary qualities of English pig iron still remains to be solved.

In Sweden and Austria the finished steel is classified by numbers, according to the hardness and percentage of carbon, commencing with the most highly carburised. The amount of carbon is determined by Eggertz's colorimetric method, described at p. 390. The following is the proportion of carbon in Bessemer steel from Heft, in Carinthia:—

No.	Specific gravity.	Carbon.	Silicon.
II.	7·791	1·35	0·02
III.	7·828	1·15	trace
IV.	7·848	0·85	0·02
V.	7·856	0·72	0·03
VI.	7·836	0·53	trace
VII.	7·872	0·11	trace

In Sweden a similar basis of classification is adopted; but instead of arbitrary numbers, the qualities are distinguished by the actual percentages of carbon.

At Seraing, in Belgium, the following scale is used. It applies only to the milder qualities.

Class.	Carbon per cent.	Tensile strength. Kilog. per sq. m.m.	Elongation. per cent.	Properties.
Extra soft	0·25—0·35	48—56	20 to 25	Welds, but does not harden.
Soft . .	0·35—0·45	56—69	10 to 20	Welds, and hardens imperfectly.
Semi-hard	0·45—0·55			
Hard . .	0·55—0·65	69—105	5 to 10	Hardens, but does not weld.

Ingots with more than 0·65 per cent. are classed as extra hard, but they are not produced in the regular system of working.

The slags of the Bessemer process vary considerably in composition from those of the puddling furnace, being much more acid and approximate to the pyroxene formula $3RO_2SiO_3$. At Hörde, in Westphalia, a crystallised slag has been obtained which yielded by analysis—

Silica	44·73
Protoxide of iron	20·59
„ manganese	32·74
Lime	1·53
Magnesia	0·17
	99·76

Oxygen, ratio of silica : bases = 23·85 : 12·43.
Specific gravity, 3·08.

The crystals were found to be of the regular augite form, the angles being intermediate between those of the natural minerals Pajsbergite and Babingtonite, as is also their composition.

The enormously high temperature developed by the action of cold air on molten cast iron in the Bessemer process is obviously due to the extreme rapidity with which the operation takes place, and the advantageous form of the converter for concentrating the heat developed. For, although the reactions, and consequently the heat produced, are in no way different from those of other finery processes, whether in the open fire or reverberatory furnace—carbon, silicon, manganese, and some iron being burnt in either case, with the productions of carbonic oxide, silicates of protoxide of iron and manganese, and malleable iron—we have, in the blowing of a charge weighing five tons, an amount of work done in about twenty minutes that would require from two and a half to three days in its performance in the puddling furnace. It has been pointed out by Jordan that the principal part of the heat developed in the process is due to the combustion of silicon, which, when oxidised to silicic acid, combines with protoxide of iron and other bases, and remains in the bath in the form of slag; while in the case of carbon a considerable portion of the heat is expended in volatilising the carbonic oxide produced, which escapes at the temperature of the melted metal, and burns to waste at the mouth of the converter. If the calorific power of silicon be assumed to be the same as that of carbon, the amount of heat produced by the combustion of one kilogramme of silicon to silicic acid will be 8,000 units* when burnt in pure oxygen, or 6,382 in air; the difference between the two quantities corresponding to the amount required to heat up the inert nitrogen. Under the latter condition, one kilogramme of carbon will produce only 475 effective units, being the difference between 2,473 units theoretically developed, and 1,998 units carried off by the gaseous products, carbonic oxide and nitrogen, supposing them to escape at a temperature of 1,400°. The use of steam instead of air as an oxidising agent, is, in the case of the combustion of iron or carbon, always disadvantageous, on account of the great amount of heat required to free the oxygen from its combination with hydrogen, which is not reproduced to the same extent in the subsequent formation of carbonic oxide or protoxide of iron. With silicon, however, the conditions are somewhat different, as there is a small sensible gain. This will explain the reason why the use of steam in the refinery is only recommended for a few minutes at the commencement of the operation—that is, as long as free silicon remains in the pig iron under treatment.

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* This is in excess of the real amount, which has recently been determined to be 7,000. Jordan's original figures are, however preserved, as the quantities are only given as approximations for the purpose of illustrating the theory of the process and not as absolute numerical determinations.

By applying the quantities given above to the calculation of the amount of heat developed in the blowing of one ton of Bessemer pig iron of the ordinary quality produced in the South of France, which is the following composition per ton of 1,000 kilog.—

Carbon	42·50
Silicon	20·00
Iron and manganese	937·50
	1000·00

Jordan arrives at the following results:—

	Kilogr.		Units of heat.
The combustion of	20	of silicon produces	127,648.
,,	42·5	of carbon produces	20,176.
,,	87·5	of iron and mang. produces	66,237.
		Or a total of	214,061.

If we take the specific heat of molten malleable iron at 0·16, the amount of heat developed will be sufficient to raise the temperature of the metal, which is supposed to be completely decarburised, about 1,350 degrees above that of the cast iron when run into the converter.

The great heating power of silicon is therefore to be regarded as the reason for the use of dark grey iron in the Bessemer process; under ordinary circumstances, about 2 or 2·5 per cent. silicon being considered as essential. Jordan states that in the steel works in the South of France the process could only be carried out by running the cast iron directly from the blast furnace into the converter, the amount of silicon being not sufficient to allow of remelting of the pigs—an operation which is usually attended with a loss of about 1 per cent. of silicon. The place of silicon as a heat-producer in the Bessemer process may be, to some extent, taken by manganese, as is the case in Styria, where the cast iron used is smelted from the spathic ores. It is, however, less advantageous, because the deficiency in silica, which is required to flux the protoxide of manganese formed, can only be supplied by the destruction of the siliceous lining of the converter. The corrosive action of manganese on the hearths of blast furnaces where spathic ores are smelted has already been noticed at p. 224.

Although silicon is an essential component of good Bessemer pig iron, it is of importance that the amount per cent. should be somewhere about the same as, or not very much more than, that of the carbon. An excess of the former element works prejudicially in two ways—first, it gives rise to an increased waste of iron in the slag; and, secondly, it cannot be completely removed before the whole of the carbon is burnt away, so that it may happen, in the blowing of such metal, that, although the process is apparently complete as determined by the usual indication of the cessation of the flame from the converter, sufficient silicon is retained in the decarburised metal to render the finished steel brittle and useless. Snelus gives the following analyses in illustration of this point :—

	I.	II.	III.	IV.
Carbon . . .	0·145	0·515	0·550	0·190
Silicon . . .	0·814	0·270	0·640	0·009
Sulphur . . .	—	—	0·067	0·033
Phosphorus . .	—	—	0·038	0·036
Manganese . .	—	—	0·554	0·576
Copper . . .	—	—	0·031	0·025

Analyses I., II., and III., are examples of underblown and brittle steel, rich in silicon; IV. is the ordinary composition of good Bessemer rail-steel made at Dowlais.

The following series of analyses, by the same chemist, of metal taken at different stages of the blow, show very distinctly the gradual removal of the carbon along with the silicon :—

	I.	II.	III.	IV.	V.	VI.
Carbon, graphitic .	2·070	—	—	—	—	—
„ combined .	1·200	2·170	1·550	0·097	0·566	0·519
Silicon . . .	1·952	0·795	0·635	0·020	0·030	0·030
Sulphur . .	0·014	trace	trace	trace	trace	trace
Phosphorus . .	0·048	0·051	0·064	0·067	0·055	0·053
Manganese . .	0·086	trace	trace	trace	0·309	0·309
Copper . . .	—	—	—	—	0·039	0·039
Ratio of carbon to silicon .	1·6 : 1	2·7 : 1	2·4 : 1	4·8 : 1	19 : 1	17 : 1

I. melted charge of pig; II. metal at end of first stage, 6 minutes from start; III. metal after blowing 9 minutes; IV. over-blown metal, 13 minutes from start, before adding spiegeleisen; V. steel from ingot; VI. steel from finished rail.

It will be noticed on comparing these analyses with the similar series from Styria given on p. 414, that the observed phenomena are substantially the same in both instances. The difference in the amount of copper, which is much larger in the Styrian steel than in that from Dowlais, is to be attributed to the fact that the pig iron used in the former is entirely smelted from spathic ore, while in the latter only the spiegeleisen is due to that source. Copper pyrites, in small quantity, is almost invariably present in spathic carbonates, and however carefully they may be roasted and weathered, some copper, as a general rule, is reduced, and passes into the iron in the blast furnace.

The progress of the conversion of the charge can be controlled to some extent by observing the spectrum given by the flame with the spectroscope; and more particularly the moment of complete decarburisation may be determined with considerable accuracy, especially if the flame be bright and free from smoke. The spectrum produced when the combustion is most active is characterised by groups of numerous lines in the yellow and green portions, that of sodium being the most prominent and the first to appear among the former. There is also a well-defined group of lines in the blue field, and under the most favourable conditions the violet and red lines of potassium and lithium, together with an extra violet line accompanying the former, are seen. For this, however, an instrument of great defining power, and an extremely bright flame are essential. When the metal is completely decarburised, the yellow and green lines disappear, but the sodium is persistent, sometimes even after the tipping of the converter. On the addition of the spiegeleisen, the whole of the lines reappear with great brilliancy. When there is much maugenese in the cast iron employed, as is the case in Styria, the use of the spectroscope is difficult, owing to the brown smoky character of the flame.

At Scraing, it has been found that the disappearance of the dark absorption-bands, which alternate with the bright lines, can be more readily determined than the latter, which often reappear after their apparent extinction, and is therefore to be preferred as admitting of much closer and easier observation.

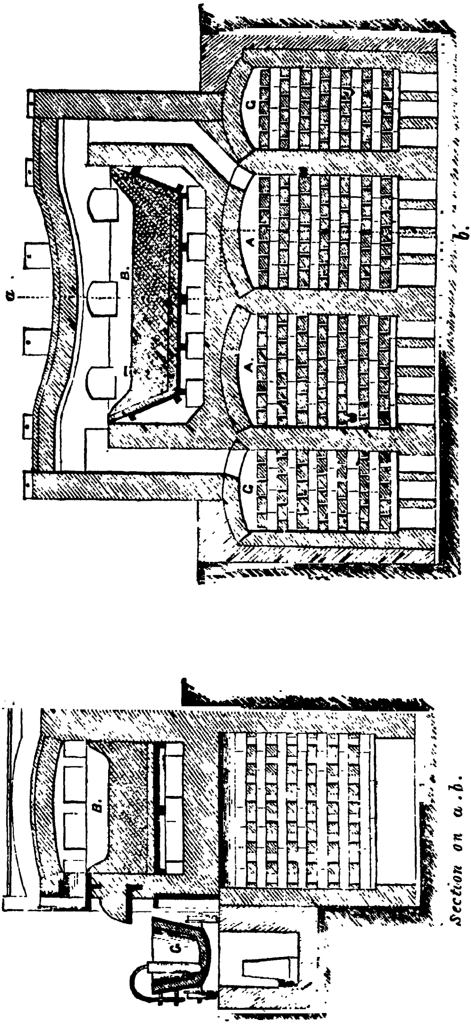
The exact chemical character of the spectrum of the Bessemer flame has not as yet been made out, although it has been the cause of considerable controversy, there being two different opinions as to its origin. One of these supposes the lines to be due to carbonic oxide and their cessation to the complete combustion of the carbon, while the other considers that they are mainly produced by manganese, and that their sudden disappearance may be accounted for by the diminution in the amount of the metal volatilised until the quantity present in the flame is reduced below that necessary to produce them, it having being found that for the detection of manganese by the spectroscope much larger quantities must be employed than are sufficient to produce the ordinary reaction with soda on platinum foil before the blow-pipe.

Another indication of the progress of the operation, is that afforded by the character of the slag. This has been employed in Austria and Sweden. An iron rod is inserted into the converter, and when brought out a portion of the slag adheres to the point. So long as any carbon remains unconsumed a peculiar brownish tint is observed, but as soon as the point of total decarburisation is reached, the slag assumes a dead black colour, with a peculiar metallic lustre characteristic of the presence of protoxide of iron in considerable quantity. This test is said to be capable of great precision in the hands of experienced workmen.

The largest series of Bessemer converters hitherto erected are those at Barrow-in-Furness. They are arranged in two groups, of which one has four converters, taking 7½-ton charges, and the other a similar number of a smaller size, holding 6 tons each. The former are 9½ feet in greatest diameter, and 14¾ feet high. In all cases the proportion occupied by the melted metal is very small as compared with the entire capacity of the converter, a large empty space being required in order to prevent the ejection of the fluid contents when the boiling is at the highest point.

In Sheffield the loss of weight on the pig iron employed is about 15 per cent., in addition to 7½ per cent. in the reverberatory melting furnace, or 22½ per cent. in all. With 3-ton converters the lining has to be renewed after blowing 250 tons; but the twyers wear out much quicker, and must be replaced after

Fig. 47.—Siemens-Martin Steel melting Furnace.



Longitudinal section through bed.

Section on a.b.

Transverse section on A B.

making 10 tons, that is, after every third or fourth operation.

The number of charges made daily is not more than four for each converter, as, although the actual blowing does not require more than fifteen or twenty minutes, a considerable time is required for the accessory operations of melting the pig iron, the solidification and removal of the castings, and the arrangement of the moulds.

The ingots, when drawn from the moulds, like those obtained from steel melted in crucibles, are always more or less unsound, and require to be compacted by hammering. For this purpose, they are raised to a bright red heat in a reheating furnace, care being taken to keep the hearth filled with smoking flame, in order to prevent the carbon from burning away. They are then hammered to a smooth face under a steam hammer, and at a second heat swaged down to the form of the first groove of the rolling mill, when intended for bars or rails. The length of the ingot is extended from 4½ to 8 feet under the hammer. In rolling rails two heats are required in addition. Spherical shot are cast a little larger than the size required, and afterwards reduced to the proper figure and dimensions by a steam hammer with hemispherical swages.

Siemens-Martin Process. The production of cast steel in the reverbatory furnace, by dissolving malleable scrap in molten cast iron according to the method proposed by Heath, Price, and Nicholson, and others has of late been brought to a considerable degree of perfection by the use of the regenerative gas furnace, which gives an intense heat without requiring an oxidizing or cutting draught, as is the case with ordinary stack-draught furnaces. The process was first carried out on a working scale by Martin of Sireuil, near Paris, who has given his name jointly with that of Siemens to the process. The furnace is represented in longitudinal and transverse sections in Fig. 46. The regenerators A A and G G are placed below the bed in the usual manner, the former being employed for heating air and the latter for gas. The bed A B is made of finely-ground quartz sand, consolidated by pressure, and strong heating, and is supported on cast-iron plates, which are kept cool by a circulation of air. The surface of the bed is flat, with a slight inclination towards the top hole, which is placed below the middle working door, on the front of the furnace. The ladle C, which has a similar arrangement for running out the steel through a hole in the bottom, to that employed on the Bessemer process, is mounted upon wheels and travels upon a railway, the ingot moulds being arranged in a straight line in the pit below.

According to the size of the furnace the charge may be from 35 cwt. to 5 tons. The materials used are good pig-iron, such as that employed for Bessemer steel making, wrought iron in the form of bars, malleable scrap, or Bessemer steel crop ends and waste, and spiegeleisen. A charge of 35 cwt. may consist of 3 cwt. of pig iron, 30 cwt. of Bessemer scrap, and 2 cwt. of spiegeleisen. The pig iron is first melted, and the malleable iron or steel is added in small quantities at a time, care being taken to raise it to a white heat by exposure to the stream of gas on the bridges before immersing it in the bath of molten cast iron.

The reversal of the gas and air valves takes place every twenty minutes. As soon as the entire charge is dissolved, a sample of the metal is taken out in a small wrought-iron ladle, and after casting is cooled in water and broken.

The heat is continued with an oxidizing flame until the assay sample, although suddenly cooled, gives a perfectly soft and tough metal, indicating the point of total decarburisation. When the spiegeleisen is added care should be taken to charge it through the hole nearest to the bridge, which, at the time is on the flue side of the furnace. When it is melted, which usually takes about twenty minutes time, the charge is stirred in order to mix the contents as uniformly as possible—an operation which must be done quickly in order to prevent loss of manganese in the slag. The contents of the furnace are then run into the ladle and cast into ingots in the usual way, the same precautions being observed as in the Bessemer process. Usually three charges are made in 24 hours. The yield per charge of 35 cwt. is from 32 to 33 cwt. of ingots, the ordinary loss being 8½ per cent., or in the most favourable case about 6 per cent. The furnace must be let down for repairs at intervals of six weeks at the longest.

This process is of great advantage for the working up of the waste of Bessemer steel works, which cannot safely be added to the charge in the converter, a plan which has been tried, but not with success. Puddled bars, made specially, cut into proper lengths, and good scrap, such as that obtained in the neighbouring tinplate forges, are the principal forms of malleable iron used in South Wales.

Another modification of the Siemens process consists in the use of finely-divided iron in the spongy state produced by the reduction of a pure red or brown hematite by a current of carbonic oxide at a red heat, instead of bars or other manufactured forms of malleable iron. This process has been superseded by the rotatory furnace described at p. 328. Finely-divided spongy iron produced in upright retorts is consolidated by immersion into melted magnetic oxide of iron, produced by the partial reduction of hematite, sufficient lime being incorporated with the mass to flux the silica of the ore. These agglomerated masses are then treated in the bath of pig-iron, producing steel directly by the oxidizing action of the magnetic oxide on the carbon in the melted metal.

Berard's Process.—This is generally similar to the Martin process; the conversion of cast iron into steel is effected by subjecting the melted metal alternately to a decarburizing and recarburizing flame, for which purpose it is necessary to employ an air blast. The operation is effected in a gas furnace with a double generator, the gas produced from coal in the first being passed through a column of coke in the second. The furnace has a deep bed and highly inclined gas-burners, and there is also a provision for blowing air through the charge from below. Hot blast is used, which is heated in cast-iron pipes by the waste flame in the flue, which is also utilized for heating up the charge and melting spiegeleisen. This process, has not as yet been employed to any great extent, and has only recently been introduced into this country.

Hardening and Tempering Steel. The property of becoming hardened by sudden cooling from a high temperature is possessed by all varieties of malleable iron containing more than 0·25 per cent. of carbon. The degree of hardness imparted by the operation is dependent partly on the amount of carbon present, and partly, but in a greater degree, on the difference of temperature between the heated metal and that of the fluid employed in hardening, and the rapidity with which the cooling takes place. Those fluids that possess the highest conducting power for heat produce the greatest hardening. Thus, mercury is most efficacious in this respect, whereas alcohol is entirely without action.

The specific gravity of steel is diminished by hardening. According to Hausmann, hard unweldable cast steel from Solingen was reduced from 7·844 to 7·760, and a softer welding quality from 7·858 to 7·801, by quenching from a red heat in cold water. The change of volume is not uniform even for objects of a regular form. Caron found, by repeating the operation on the same bar for many times in succession, that hammered bars contracted in length and increased in the other dimensions. With rolled bars and sheets, on the other hand, an increase in length was observed. After thirty hardenings, the specific gravity was diminished from 7·817 to 7·743.

The process of tempering consists in reheating hardened steel to a temperature varying with the degree of hardness required, and cooling it by immersion in the same manner. The proper temperature is indicated by the colour of the thin film of oxide formed on the surface of the heated steel, according to the following scale :—

Temperature.	Colour.	Proper temper for
220°	Pale yellow.	Lancets.
230	Straw yellow.	Razors and surgical instruments.
243	Golden yellow.	Common razors and penknives.
255	Brown.	Cold chisels, shears, scissors.
265	Brown dappled with purple.	Axes, planes, &c.
277	Purple.	Table knives, large shears.
288	Bright blue.	Swords, coiled springs.
293	Full blue.	Fine saws, augers, &c.
316	Dark blue.	Hand and pit saws.

The reheating is generally effected in baths of molten metals, or metallic alloys having definite fusing points. Thus, alloys of tin and lead, in varying proportions, may be used up to a temperature of about 300°; above which, boiling linseed oil and pure lead are to be employed.

The tenacity of steel is very highly increased by tempering with oil instead of water.

CHAPTER XIX.

ANALYSIS OF CAST AND WROUGHT IRON AND STEEL.

THE chief points required to be determined in the analysis of the different kinds of metallic iron for commercial purposes are carbon, distinguishing the graphitic from that in the combined state, silicon, sulphur, phosphorus, manganese, and copper, while the remaining common heavy metals, and those of the alkaline earths, are of less importance, as occurring only in minute quantities, and requiring the use of refined analytical methods, which involve too great an expenditure of time and materials to be employed except in special inquiries.

Determination of the Total Amount of Carbon. When iron containing carbon in the state of combination is dissolved in hydrochloric acid, protochloride of iron is formed with the evolution of hydrogen, which in the nascent state combines with a portion of the carbon set free, at the same time forming volatile hydrocarbons, which escape, giving a fetid odour to the gas. If, however, instead of hydrochloric acid, a metallic chloride, reducible by iron, is used, no evolution of hydrogen takes place, and the whole of the carbon goes down in an insoluble form, and may be collected. The uncombined or graphitic carbon is not in any way attacked by the acid. The reagent generally used is protochloride of copper, CuCl, which was first introduced by Berzelius. About 100 grains of the metal in a finely-divided state, usually drill chips, borings, or filings, are treated with a moderately strong solution of protochloride of copper until the whole is decomposed. Protochloride of iron is formed, and metallic copper, which remains undissolved, together with the carbon and silicon. The insoluble residue is collected on a filter, and washed, first with weak hydrochloric acid, then with a solution of potash, and lastly, with water, leaving only the carbon and copper behind, which, when dried, are burnt with oxide of copper in a hard glass tube, according to the ordinary method adopted in organic analysis. As the graphite is difficultly combustible, it is best to burn it off in a current of free oxygen. The total amount of carbon is deduced from the carbonic acid produced in the combustion, which is absorbed by caustic potash in the usual way. In Richter's modification of the above process a solution of the double chloride of copper and sodium, NaCl + CuCl, is employed instead of chloride of copper alone. By properly proportioning the amount of the double salt employed, the separation of metallic copper may be prevented, which is retained in solution as subchloride.

Regnault's method of burning the iron directly with oxide of copper, or chromate of lead, can only be adopted when the substance under examination is susceptible of being reduced to a fine powder, an operation of considerable difficulty with many varieties of iron. Weyl's method, which does not require the sample to be powdered, consists in effecting the solution of the iron with hydrochloric acid, aided by a weak galvanic current. A lump of the iron to be treated is partly immersed in weak hydrochloric acid in connection with the positive pole of a single Bunsen cell, the negative pole being formed by a plate of platinum. The distance between the poles must be regulated so that no sesquichloride of iron is formed, a point that may be readily determined by the appearance of a yellow tint in the liquid. As soon as the immersed portion of the iron is dissolved the remainder is removed, washed, dried, and carefully weighed: the difference or loss on the original weight gives the amount of iron dissolved. The carbon and other insoluble matters are collected on an asbestos filter, and treated in a similar manner to that already described.

Ullgren's method depends upon the oxidation of the total amount of carbon to carbonic acid without heat by means of chromic acid. The first operation consists in treating the finely-divided iron with sulphate of copper, producing metallic copper and protosulphate of iron, carbon and other insoluble substances being precipitated. The precipitate is washed by decantation, and removed into a flask with the smallest possible quantity of water. Strong sulphuric acid is then added, and after the liquid has cooled, a certain quantity of chromic acid, which is decomposed by the carbon, producing carbonic acid, which is collected in a weighed tube containing caustic potash in the usual way. This method was reputed to give good results, but, according to Schnitzler, is not available for the analysis of steel, the results indicated being inferior in accuracy to that of Berzelius, and in some instances as much as 30 per cent. too low on the total amount of carbon contained.

	I.	II.	III.	IV.	V.	VI.	VII.
Combined carbon, per cent. .	—	—	—	—	—	0·19	0·18
Graphitic " " .	—	—	—	—	—	0·78	0·74
Total carbon . . .	0·74	0·75	0·68	0·93	0·96	0·92	0·92

Nos. I., II., III. Determinations by Weyl's method. Nos. IV., V. By Berzelius's method with chloride of copper. Nos. VI., VII. By Fresenius's method of determining the combined carbon directly. The latter is not applicable to such irons as contain a large amount of combined carbon, such as spiegeleisen, which, when dissolved in acid, deposit hydrocarbon oils that are not carried off by the hydrogen evolved.

Boussingault uses bichloride of mercury in the determination of carbon, for the solution of the iron, which is converted into protochloride of iron, without the decomposition of water, so that no gas is given off capable of combining with the carbon as it is liberated, and the consequent formation of volatile hydrocarbons is avoided. The iron, finely powdered or in filings, mixed with fifteen times its weight of bichloride of mercury and sufficient water to form a thin paste, is triturated in an agate mortar for half an hour. When thoroughly incorporated, the paste is transferred to a hard glass flask, and heated to 80° or 100° for an hours, when it is thrown on a filter and washed with warm water, to remove the soluble protochloride of iron. The residue on the filter, consisting of protochloride of mercury, with carbon and the other insoluble matters of the iron, is dried in a water-bath, transferred to a platinum boat, and introduced into a tube communicating with a generator or gas-holder supplying a stream of dry hydrogen. The tube is gradually heated to redness, when the protochloride of mercury is volatilised without decomposition, leaving the carbon in the form of a black powder, which is allowed to cool in hydrogen, and then weighed. When the boat is slightly heated, the carbon fires in the air and burns like tinder; if, however, graphite is present, it must be burnt in a current of oxygen. The siliceous residue, after the combustion of the carbon, is due to the combined silicon of the iron, but the quantity obtained does not represent the whole amount, because the first action of the bichloride of mercury is to produce chloride of silicon, which is transformed by water into hydrochloric acid and silica, and the latter being partly in the soluble form, passes away with the wash-water, in the filtration.

Graphite, or uncombined carbon, is determined in the insoluble residue remaining after solution in hydrochloric acid, which is digested with a strong solution of caustic potash to remove the silica produced from the oxidation of the silicon. The black residue, after the solution of the silica, is repeatedly washed until perfectly free from alkali, dried, weighed, and calcined at a strong red heat in a current of air until the whole of the carbonaceous matter is burnt off. The weight of the small amount of residue is then determined, and deducted from that obtained previously. The difference gives the quantity of graphite. The combined carbon is obtained by deducting the last result from that of the total amount of carbon obtained by one of the preceding methods.

Silicon is determined by weighing the insoluble residue of the hydrochloric acid solution after it has been ignited to a strong red heat in a current of air to remove the whole of the carbon. This residue is nearly all silica, but its purity must be tested by dissolving in caustic potash. The insoluble portion, if any, is collected, and its weight is deducted from that obtained at the former weighing.

Determination of Phosphorus. A weighed portion of the metal is digested in aqua regia, evaporated to dryness, and the residue redissolved in hydrochloric acid. The solution is then treated in precisely the same manner as has already been described in the analyses of iron ores, the determination being made as pyrophosphate of magnesia.

Sulphur may be estimated in grey pig iron by collecting the sulphuretted hydrogen gas evolved by the action of hydrochloric acid, and passing it through a solution of acetate of lead. The precipitate, sulphide of lead, is collected, washed, and converted into sulphate by digesting with nitric acid, evaporation to dryness, and gentle ignition. The amount of sulphur is calculated from the weight of sulphate of lead so obtained: it contains 10·55 per cent. of sulphur. The above is not applicable to white iron, owing to the difficulty of acting upon it with hydrochloric acid; but aqua regia may be used, and the sulphur is then directly converted into sulphuric acid, and may be precipitated with chloride of barium, and weighed as sulphate of baryta in the usual way. Another method of oxidising the sulphur consists in fusing the finely-divided metal with nitre and carbonate of soda in a gold crucible; the fused mass is extracted with water, and the sulphuric acid existing in the solution as an alkaline sulphate is precipitated by chloride of barium as before.

It is rarely necessary to determine the amount of iron, except in the case of a complete analysis, for the purpose of controlling the results. It may be most conveniently done by means of one of the two volumetric methods described under the head of Assaying.

Manganese is determined in the manner as described in the analysis of ores. Arsenic and copper are precipitated from the hydrochloric acid solution by sulphuretted hydrogen, care being taken to reduce the whole of the iron to the state of protochloride. The two sulphides may be separated by digestion in sulphide of potassium, which dissolves the sulphide of arsenic, leaving the sulphide of copper untouched.

Nickel and cobalt, if present, will be found in the solution obtained after the removal of arsenic and copper by sulphuretted hydrogen. The iron is first converted to a persalt, and is then separated as peroxide by a slight excess of carbonate of baryta; after which nickel and cobalt are precipitated by sulphide of ammonium.

Chromium and vanadium are to be looked for in the carbonaceous residue obtained by dissolving a considerable quantity of the iron in weak acid. The ignited residue is fused with nitre at a gentle heat for an hour, and when cooled, the mass is powdered and boiled with water. Vanadate and chromate of potash pass into the solution, are converted, by means of chloride of barium, into the corresponding baryta salts, which are insoluble, and are collected upon a filter. The chromate and vanadate of baryta are decomposed with sulphuric acid, whereby chromic and vanadic acid, are set free, and remain as such in the filtrate after separation from the sulphate of baryta. The filtrate is neutralised with ammonia, concentrated by evaporation, and a fragment of chloride of ammonium is placed in it. In proportion as the solution becomes saturated by the latter salt, vanadate of ammonia is deposited as a white or yellowish crystalline powder, which may be collected and subjected to further treatment by the blowpipe or otherwise, in order to verify its properties. The chromic acid is precipitated from the solution by means of acetate of lead as a yellow chromate of lead.

Eggertz's methods of determining small quantities of sulphur and phosphorus may be conveniently used for estimating these substances in pig irons of high quality, such as those produced in Sweden, but are not applicable to the bulk of the iron produced with mineral fuel from the ores of stratified deposits.

For sulphur, one-tenth of a gramme of finely-divided pig iron is placed in a stoppered bottle, with 1 gramme of water and half a gramme of sulphuric acid. A clean bright plate of silver is suspended by a wire in the upper part of the bottle, and the discoloration in a given time (about fifteen minutes) is proportional to the amount of sulphuretted hydrogen evolved. As this is very small, the plate, instead of being blackened, is tarnished with thin films, presenting the same order of colour as those observed in tempering steel according to their thickness, varying from straw-yellow to bright blue. No absolute measure of quantity is obtained, the results being determined by comparing the colour on the plate with a standard series, obtained previously by experimenting upon samples whose composition has been determined by analysis.

Thus a blue colour indicates that the metal will yield a sensibly red-short iron when converted into malleable iron in the hearth finery; but if the plate is only browned, the sulphur is not in sufficient quantity to affect the quality of the iron.

In the determination of small quantities of phosphorus, 1 gramme or 15 grains of the iron or steel to be examined is reduced to a fine powder, and treated with strong nitric acid at the heat of boiling water. When the metal is dissolved, the solution is evaporated to dryness, the residue moistened with 4 cubic centimetres of aqua regia made of equal volumes of hydrochloric and nitric acids. After standing for about an hour, an equal volume of water is added, and the solution filtered. The filtrate and wash-water should not exceed 20 cubic centimetres.

The precipitation of the phosphoric acid is effected by a solution of molybdate of ammonia, containing 60 milligrammes of molybdic acid per cubic centimetre. It is added to the solution of the iron in the proportion of 2 cubic centimetres per milligramme of phosphorus supposed to be present, and digested, with occasional stirring, at about 40° for three hours. If no precipitate is formed, a further addition of molybdate of ammonia is made. The yellow crystalline precipitate, which contains 1·63 per cent. of phosphorus, is collected in a filter, washed with water acidified with nitric acid, and weighed after drying in a water bath. If, however, the quantity is very small, the determination may be made by measuring the volume of the precipitate in a narrow glass tube with a scale made especially for the purpose.

The whole of the necessary materials for determining sulphur and phosphorus by these methods is supplied with the apparatus made in Sweden for the assay of iron ores by the dry way in the small crucibles mentioned previously.

Eggertz's method of determining combined carbon in iron or steel depends upon the discoloration produced by carbon in solution of pernitrate of iron, which, under ordinary circumstances, is colourless, or at most of a slightly greenish tint. The standard series of colours is made by dissolving quantities weighing 1 decigramme of steel of known composition in nitric acid at a low temperature, and diluting with water to a standard volume. The solutions, which give different shades of brown, are preserved in glass tubes.

A similar weight of the steel to be examined is dissolved in pure nitric acid under the conditions observed in making the standard series. The solution is decanted from the residue, poured into a burette of the same diameter as the tubes containing the standard series, and diluted with water until it matches one of the tints. The amount of carbon is then found by calculation from the relative volumes of the solutions. Steel, with a medium amount of carbon, say 0·8 per cent., gives a yellowish-green solution; a very hard variety, with 1·5 per cent., brownish red; and the softest, with 0·40 per cent., only a slight greenish tinge.

The Swedish classification of Bessemer steel by numbers, based upon the percentage of carbon determined by the above process, is as follows:—

No. 1 contains 2 per cent.; No. 1·5, 1·75; No. 2, 1·5; and so on up to No. 4·5, with only 0·25 per cent., below which point the scale is not extended.

The following determinations of carbon in various kinds of iron and steel made in Sweden are by Eggertz:—

Softest Swedish Bessemer iron	contains	0·08	per cent.	of carbon.
Soft steel	„	0·75	„	„
Best quality of cast steel .	„	1·4 to 1·5	„	„
Natural forge steel	„	0·99 „ 2·44	„	„
Cement steel	„	0·5 „ 1·90	„	„
Cast steel	„	0·86 „ 1·94	„	„
Hardest welding cast steel .	„	1·80	„	„
Malleable cast iron	„	0·88 „ 1·52	„	„
Draw-plate steel	„	3·30	„	„

The following modification of this process is adopted at Seraing, in Belgium, for the determination of carbon in mild Bessemer steel. Two samples, each weighing 0·2 grammes, of the ingot to be tested are taken; one being in the state of filings, and the other of borings. These are treated with 20 cubic centimetres of nitric acid, of specific quartz 1·2; the solution being effected in a water-bath at 80°. For the test-standard the same weight of two different samples, of the hardest steel made in the works, whose carbon has been already determined, and containing 0·61 and 0·63 per cent. respectively, are dissolved up in the same manner. The whole of the four solutions are then brought down to one tint by adding water to the darker ones, care being taken to conduct the operation in tubes of exactly the same diameter. The amount of carbon can then be computed from the volume of the solutions. If the difference in the results given by the two samples does not exceed 0·03 per cent., the arithmetical mean between them is adopted as the true amount; but should it be larger, the operation is repeated.

In order to obviate the necessity of making standard solutions for every set of determinations, different coloured legends have been employed with a view of obtaining a permanent scale of colours. Among these may be mentioned caramel, or burnt sugar, which gives various shades of yellow and brown, but alters very quickly; and partially decomposed solution of indigo in sulphuric acid, which is said to keep its characteristic colour without alteration for a considerable time. Another recommended by Hetman consists of a mixture of bichromate of potash and nitrate of cobalt. In most cases, however, the direct system of comparison with solutions obtained from steel of known compositions is to be preferred.

Silicon. The determination of silicon in iron and steel is a matter of some difficulty, as the mere weighing of the ignited insoluble residue from the hydrochloric acid solution and calculation of the silica found, as silicon, depends upon the assumption that the iron is free from silicates, which is often contrary to the fact, especially in malleable iron, which may contain a notable amount of intermingled slag that has not been perfectly expelled in the welding, and exists as a mechanical inpurity, having no relation whatever to the real composition of the metal. This defective interpretation of the ultimate analyses is probably the cause of the contradictory statements current as to the amount of silicon that may be present beneficially in malleable iron. Eggertz has introduced a method of determining silicon in the presence of slags, which is based upon the fact that when iron is slowly acted upon by bromine, a solution of iodine, it dissolves, and the silicon set free is converted into silica, which is completely soluble in a boiling solution of carbonate of soda, while that in combination in the slag, if any be present, is not acted upon. The same method may be employed with cast iron, as blast furnace slag, which sometimes occurs in it as a mechanical impurity is not sensibly acted upon either by iodine, bromine, or carbonate of soda.

The process is conducted as follows. Three grammes or ·45 grains of iron in the state of filings or borings, sufficiently small to pass through a sieve with meshes $\frac{1}{70}$ of an inch indiameter, is treated with five times its weight of iodine, in a volume of fifteen cubic centimetres of water contained in a beaker of about six or seven times that capacity. Water that has been boiled to free it from air is used, and the operation must be performed at as low a temperature as possible, in order to prevent oxidation of the iron by the air, it is usual, therefore, to keep the beaker cool by the use of ice. When the iron is completely dissolved, the solution is increased to three times the original volume by the addition of very cold water in order to prevent the separation of basic salts of iron, and is well stirred and left to settle. The lighter scales of graphitic carbon remain in suspension, and are poured off with the bulk of the liquid into a filter 2 inches in diameter, with only about one-tenth of the original quantity of the insoluble residue which forms a heavy powder at the bottom of the beaker. A few drops of hydrochloric acid are added, and the liquid stirred with a glass rod: if this produces a disengagement of gas the whole of the iron is not dissolved, and a little iodine and carbonate of soda is added in order to complete the solution. The acidified water must be poured quickly on the filter in order to prevent the decomposition of the slag. When the whole of the residue is transferred to the filter it is washed with cold water until the whole of the iron is found to be completely removed when tested by a solution of ferrocyanide of potassium. The filtrate is evaporated to dryness with the addition of hydrochloric acid in order to recover any small amount of silica that may have gone into solution with the iron. The original residue which may contain graphite, silica, and slag is transferred without drying into a large platinum crucible, and after concentrating the wash-water to 6 cubic centimeters, a saturated solution of carbonate of soda is added, and the crucible is heated for one hour in a water-bath, the liquid being stirred from time to time with a platinum spatula in order to divide any lumps in the insoluble residue. The solution is then carefully poured from the insoluble mass in the crucible on to a small filter, and a fresh quantity of carbonate of soda solution is added and boiled for another hour, when the whole contents of the crucible are thrown upon the filter and washed. The alkaline solution of silica is acidified with hydrochloric acid, added to that containing the iron, and evaporated to dryness in a water-bath. This operation is repeated with the addition of fresh acid until the silica is perfectly freed from iron, when it is filtered, dried, ignited, and weighed as often as may be necessary to ensure its complete purity, which must be further tested by heating it with hydrochloric acid. When 3 grammes of iron are treated, 0·016 grammes of silica correspond to 0.001 gramme of silicon. The insoluble residue from the carbonate of soda solution may contain graphite slag, oxide of iron, and titanic acid. There is no way of distinguishing the amount of oxide of iron present as such, in addition to that in combination with silica, except by assuming the composition of the slag to be constant, which is not the case.

Eggertz found by the use of this process, that the amount of silicon in good bar iron may vary from 0·01 to

0·10 per cent.; but in two samples of Krupp's cast steel it was as high as 0·30 per cent. Slag has been found usually in mere traces in cast steel, but in one instance it amounted to 0·2 per cent. Malleable iron, however, contained much more. In wire iron from a charcoal hearth 0·33 per cent. was found, in armour-plates from 0·75 to 3·00 per cent., and in a rail as much as from 4·00 to 5·00 per cent.

Mechanical Properties and Tests of Malleable Iron and Steel. The appearance of the fractured surface of malleable iron is partly dependent upon the manner in which the breaking strain is applied, and partly upon the nature and method of manufacture of the sample. The most highly crystalline appearance may be obtained by sudden fracture; but when the strain is so applied as to overcome the cohesion of the particles gradually, the elementary crystals are drawn out to a certain extent before yielding; and the result is a finely-granular fibrous surface, like that produced by the cross section of a bundle of wires not all broken through at the same point.

The crystalline structure of pure melted, or any other variety of malleable iron, may be modified by the process of lamination; the crystals giving way and becoming elongated by the action of the rolling mill, fibre being developed in the direction of the length of the bar. At each successive piling the grain becomes finer and more regular, owing to the breaking down and rewelding of the fibres in the bars forming the pile. Tresca has properly compared the effect of forge rolling to that of the processes of carding and drawing cotton, as far as regards the sorting of the fibres into parallelism. The specific gravity of malleable iron is diminished by a powerful tractive force, such as is excited in wire-drawing or cold rolling, as the transverse action does not diminish in proportion to the elongation; at the same time, the metal is hardened, and its tenacity is considerably increased. By annealing, the softness and lower tensile strength may be restored. The following results, taken from Kirkaldy's experiments on wrought iron and steel, show the relation between the specific gravity and tensile strength of the same class of wrought iron under varying conditions of manufacture and treatment. The diminution in specific gravity in bars stretched by a severe tensile strain varied from 0·7 to 1·2 per cent. By cold rolling the diminution amounted to 0·7 per cent. for bars, and 0·36 per cent. for plates.

Mark or Name.	Specific Gravity.	Tensile Strength.
Govan puddled bar . . .	7·450	20·9 tons per square inch.
„ hammered bar . .	7·764	28·7 „ „
„ rolled bar, 1½ inch square	7·720	25·6 „ „
„ „ reduced to 1¼ inch	7·729	25·4 „ „
„ „ „ 1 „	7·722	25·6 „ „
„ „ „ ¾ „	7·702	25·9 „ „
„ „ „ ½ „	7·685	26·6 „ „
Blochairn best rolled bar . .	7·636	27·1 „ „
„ „ cold rolled . .	7·582	30·6 to 30·5 „
„ „ annealed . .	—	25·2 to 27·8 „
„ best boiler plate .	7·566	20·5 lengthways 19·2 crossways
„ „ cold rolled	7·539	39·7 lengthways 36·0 crossways
„ „ annealed	—	22·7 lengthways 21·7 crossways

The following table contains the relation between the specific gravity and tensile strength of Bessemer steel of various degrees of carburisation made at Sandviken, in Sweden:—

Percentage of Carbon.	Specific gravity. Soft.	Hardened.	Tensile strength, tons per square inch.
1·5	7·785	7·736	34—39
1·2	7·832	7·771	37—40
0·9	7·874	7·808	56—59
0·6	7·879	7·807	37—41
0·4	7·893	7·839	30—34

The absolute strength appears to be greatest when the steel contains from 1 to 1¼ per cent. of carbon.

According to Kirkaldy's experiments, the tensile strength of the best brands of British bar iron varies from 24 to 27·5 tons per square inch : bars of irregular section bear a somewhat smaller strain, or from 20 27·4 tons. The strength of plates varies from 20·4 to 24·6 tons lengthways, or in the direction of the greatest longitudinal extension produced by rolling, and from 18·5 to 22·6 tons crossways. The specific gravity varies from 7·531 to 7·760, being greatest in Yorkshire iron, which is made almost entirely under the hammer.

The relation between the composition of malleable iron and its tenacity has not yet been completely worked out. The elaborate mechanical experiments of Kirkaldy have, unfortunately, not been supplemented by analyses of the iron tested. The following table, containing the limits of elasticity and tensile strength of various kinds of malleable iron and steel, is taken from a large series of determinations made in Sweden for the Jernkontor, by Styffe :—

Quality of Iron.	Percentage of Carbon.	Percentage of Phosphorus	Modulus of Elasticity per square inch.	Breaking strain per square inch.
Högbö Bessemer steel, rolled bar	2·16	—	29·8 tons	40·2 tons
"	1·85	—	26·7 "	46·2 "
Wikmanshytta Uchatius steel "	1·22	—	33·8 "	66·9 "
Carlsdal Bessemer steel . . .	1·19	—	31·4 "	64·8 "
" Uchatius " . . .	1·16	—	33·2 "	64·7 "
Högbö Bessemer " . . .	1·14	0·018	39·6 "	59·0 "
" " hammered .	0·68	—	31·8 "	46·8 "
Krupp's cast steel " .	0·62	0·020	23·7 "	39·5 "
Högbö Bessemer iron " .	0·33	—	24·1 "	33·0 "
Low Moor rolled tire bar . .	0·21	0·068	16·7 "	27·3 "
Lesjoförs rolled bar made in the Lancashire hearth .	0·06	0·022	14·0 "	22·5 "

The tensile strength alone is not a sufficient measure of the quality of malleable iron, as a metal of great strength may be deficient in softness, and incapable of being forged. This is tested by hammering the sample both hot and cold, when it should bend without fracture to a certain amount, the angle varying with the temperature and thickness of the metal. The resistance of rails to percussive strain is tested in the following manner :—The rail under trial is placed horizontally, and keyed fast in the jaws of a pair of chairs about 3 feet apart, attached to a heavy anvil. A heavy weight is then allowed to fall from a considerable height, so as to strike the top flange midway between the points of support. At Sheffield, steel rails are subjected to the action of a pile ram or monkey weighing 20 cwt., which is allowed to fall from a height of from 20 to 30 feet. The quality of the welding may be best rendered apparent by etching a polished surface with acid.

The following are the tests prescribed by the Admiralty for plate iron intended for use in the navy, and may be taken as indicating the average strength of iron of fair quality :—

PLATE IRON, FIRST CLASS, OR B.B.			SECOND CLASS, OR B.	
	Lengthways.	Crossways.	Lngthwys.	Crossways.
Tensile strength, per square inch,	22 tons	18 tons	20 tons	17 tons
Forge test, hot. All plates of 1 inch in thickness and below must be capable of bending hot without fracture through an angle of	125°	90°	90°	60°
Forge test, cold. Plates should admit of bending cold without fracture as follows :—				
1 in. in thickness to an angle of	15	5	10	—
$\frac{3}{4}$ " "	25	10	20	5
$\frac{1}{2}$ " "	35	15	30	10
$\frac{1}{4}$ " "	70	30	55	20
$\frac{3}{16}$ inch and under "	90	40	75	30

Plates should be tested, both hot and cold, on a cast-iron slab having a fair surface, with an edge at right angles, the corner being rounded off with a radius of half an inch.

The portion of plate tested to be 4 feet in length across the grain, and the full width of the plate with the grain. The bend should be made at from 3 to 6 inches from the edge.

All plates to be free from lamination and injurious surface defects.

The tests to be applied to one plate of each lot of fifty of the same thickness.

SUPPLEMENTARY NOTES.

CLEVELAND BLAST FURNACES.

The following table recently published by Gjers shows the progressive increase in size in the Cleveland Blast Furnaces, giving their dimensions and capacity in the order of their respective dates :—

Date.	Name of Firm.	Furnaces.	Height.	Width of boshes.	Capacity.
		No.	Feet.	Feet.	Cubic feet.
1851	Bolckow and Vaughan.	3	42	15	4,566
1853	Bell Brothers.	6	47½	16½	6,174
,,	Bolckow and Vaughan.	6	54	15	7,166
,,	Gilkes, Wilson, and Co.	2	45½	14½	5,100
1854	Cochrane and Co.	4	55	16	7,175
,,	B. Samuelson and Co.	3	50	14	5,050
,,	Bolckow and Vaughan.	3	54	15	7,116
,,	Gilkes, Wilson, and Co.	2	55	14½	6,800
1856	Stockton Furnace Co.	3	50	16	6,341
,,	Norton Iron Co.	3	50	15	6,000
1858	Thomas Vaughan.	6	56	16	7,000
,,	Hopkins, Gilkes, and Co.	2	56	16	7,200
,,	Jones, Dunning, and Co.	2	58	17	8,000
,,	Bolckow and Vaughan.	1	61	16⅓	7,960
1861	Gilkes, Wilson, and Co.	1	55	16	7,700
,,	William Whitwell and Co.	3	60	20	12,778
1862	Bolckow and Vaughan.	2	75	16½	11,985
1864	B. Samuelson and Co.	4	69	20	15,500
,,	Lloyd and Co.	4	67	20	15,000
,,	Thomas Vaughan.	6	81	19	16,000
,,	Stevenson, Jacques, and Co.	8	70	22	17,000
1865	Gilkes, Wilson, and Co.	2	75	21	17,700
,,	Bell Brothers.	2	80	20½	15,500
,,	Bolckow and Vaughan.	2	95½	16	15,050
1866	Bolckow and Vaughan.	1	75	20	12,972
,,	Hopkins, Gilkes, and Co.	2	75	24	20,000
,,	Swan, Coates, and Co.	2	75	20	16,090
,,	Bell Brothers.	2	80	17	11,500
1867	Norton Iron Co.	2	85	25	26,000
,,	Cochrane and Co.	2	76	23	20,624
1868	Gilkes, Wilson, and Co.	1	75	24	22,500
,,	Stevenson, Jacques, and Co.	1	70	23	18,000
,,	B. Samuelson and Co.	1	69	21½	16,000
,,	Lloyd and Co.	2	80	21½	18,000
,,	Jones, Dunning, and Co.	8	73	18	12,000
,,	Bolckow, Vaughan, and Co.	2	95½	22	25,940
,,	Bolckow, Vaughan, and Co.	1	95½	23	28,800
1869	Thomas Vaughan.	3	85	25	26,000
1870	Bell Brothers.	4	80	25	25,000
,,	Stockton Furnace Co.	2	80	24	24,613
,,	Swan, Coates, and Co.	1	75	23⅔	22,229
,,	Cochrane and Co.	2	90	30	41,149
,,	Gilkes, Wilson, and Co.	2	85	27	32,000
,,	B. Samuelson and Co.	2	85	28	30,000
1871	Bolckow, Vaughan, and Co.	2	95½	24	28,950
,,	Lackenby Iron Co.	2	85½	25½	26,670
,,	Gjers, Mills, and Co.	2	85	25	26,000

NOTE TO PAGE 92.

For the following analysis of "purple ore," I am indebted to Mr. J. A. Phillips, the managing director of the Widnes Metal Company. It is obtained from the residues of cupriferous iron pyrites, which have been treated for sulphur in the manufacture of sulphuric acid, calcined with an addition of salt, and lixiviated with water, in order to save the copper, which is removed as a soluble chloride, and is precipitated as cement copper by running the solution into vats, containing scrap iron. The residue of these operations is nearly pure peroxide of iron in the form of a heavy purplish-red powder, having the following composition:—

Peroxide of iron	96·00
Lead (as sulphate)	0·75
Copper	0·20
Sulphur	0·36
Phosphorus	None.
Lime	0.40
Soda	0·10
Cobalt, arsenic, and chlorine	Traces.
Insoluble residue	2·11
Metallic Iron	67·00

The results are computed in the dry state, but, as ordinarily sold, the ore contains about 15 per cent. of water. It is principally used for fettling puddling furnaces, but is also smelted to some extent, being added to the charge in the blast furnace in the proportion of 25 per cent. of the amount of solid ore.

COMPOSITION OF THE GASES OF THE BESSEMER CONVERTER.

The nature of the gases evolved during the blowing of a charge of Bessemer steel has recently been investigated by Mr. G. J. Snelus, who has given the following tabular statement of the composition of the gas at different periods of a blow lasting eighteen minutes.

	I.	II.	III.	IV.	V.	VI.
Time from starting	2 min.	4 min.	6 min.	10 min.	12 min.	14 min.
Carbonic acid	10·71	8·57	8·20	3·58	2·30	1·34
Carbonic oxide	none.	3·95	4·52	19·59	29·30	31·11
Oxygen	0·92	—	—	—	—	—
Hydrogen	88·37	0·88	2·00	2·00	2·16	2·00
Nitrogen		86·58	85·28	74·83	66·24	65·55
	100·00	100·00	100·00	100·00	100·00	100·00

On examining these results it is found that the oxygen corresponding to the nitrogen in Analysis I. is sufficient to oxidize not only the

4·43 parts by weight of carbon that are contained in the gas, but also 11·91 parts of silicon, and this is actually the proportion in which these two substances are eliminated from the iron, as proved by analysis of samples of metal taken at this stage. Analysis III. shows that 5·27 parts of carbon are burnt along with 11·74 of silicon. Analysis IV. of gas taken after the commencement of the boil, shows a different result; the large proportion of carbonic oxide accounts for the increased luminosity of the flame, and the removal of carbon proceeds in the ratio of 9·6 parts of 6·25 of silicon. No. V. was specially tested for hydrocarbons, but none were found. No. VI. gives the proportion of 13·45 of carbon oxidized to 0·46 of silicon, thus confirming what has already been made out by analyses of the metal, that the last traces of silicon are oxidized very slowly.

Snelus considers that the production of carbonic acid during the first part of the blow, and carbonic oxide at a later stage, is due to the increase of temperature during the blow, and that the result agrees with those of the experiments of J. L. Bell, who found that at a low temperature carbonic acid, in contact with iron, was more stable than carbonic oxide; but that at a high temperature, the reverse was the case. He also considers that the continuous spectrum produced by the flame at the commencement of the blow is to be accounted for by the fact that at this period there is no true flame, but only a stream of gases containing white hot solid matter in suspension, while at the same time the temperature is not sufficiently high to give the spectrum of carbonic acid. Later on in the blow, when there is an abundance of carbonic oxide burning at the mouth of the converter, the temperature is extremely high, and consequently a carbon spectrum is produced which is distinct from other carbon spectra yet seen, because the spectrum of carbonic oxide has not yet been observed at the particular temperature of the Bessemer flame. The heating power of the gas in the latter part of the blow is fully equal to that of the blast furnace, or Siemens' producer, and Snelus computes that in works blowing 1,000 tons of pig iron per week, an amount of heat is wasted, which supposing it could be utilised, would correspond to a saving of 25 tons of coke per week.

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